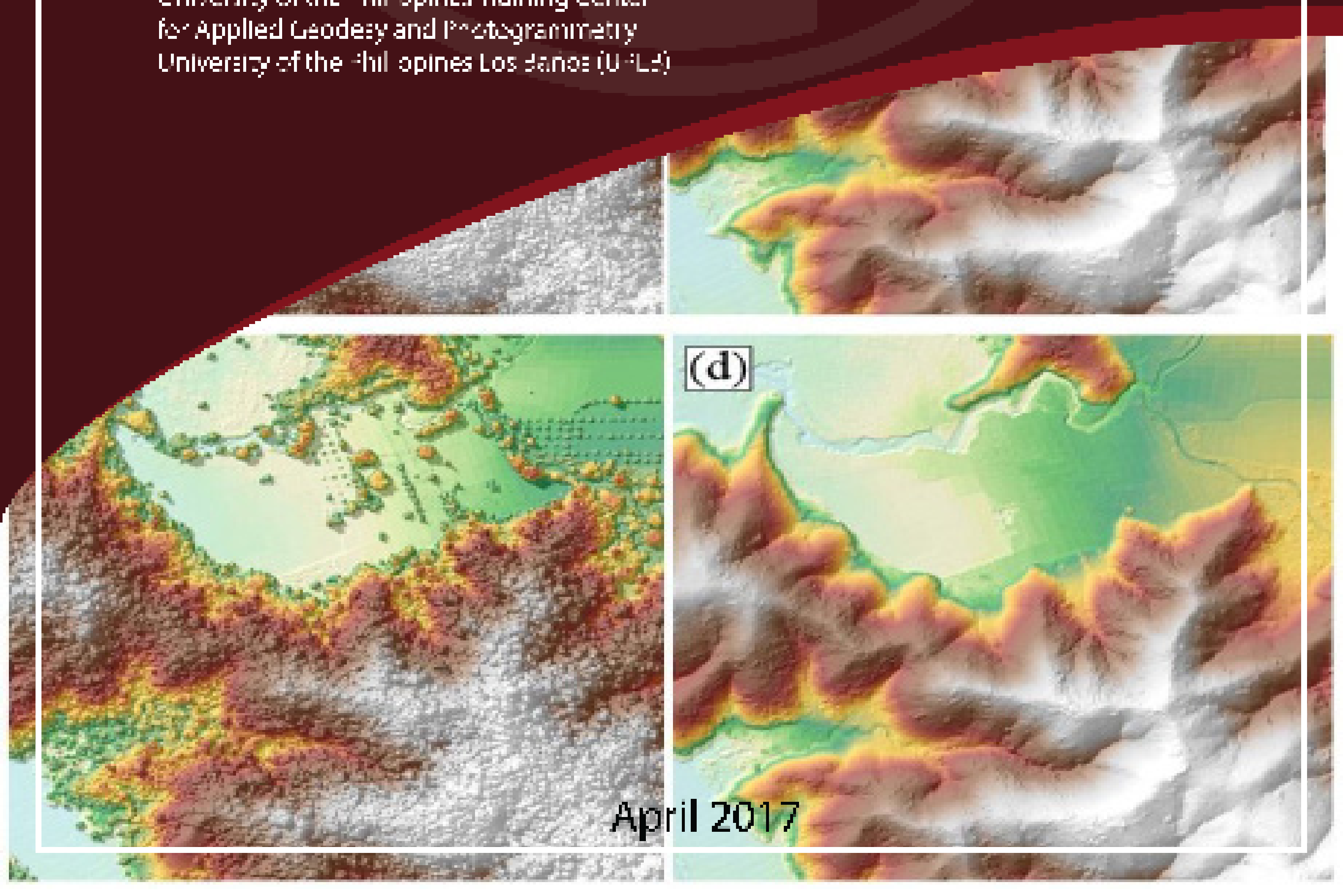
HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR 1)

LiDAR Surveys and Flood Mapping of Mamburao River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
University of the Philippines Los Baños (UPLB)



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AAC	Asian Aerospace Corporation
Ab	abutment
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
ATQ	Antique
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
DOST	Department of Science and Technology
DPPC	Data Pre-Processing Component
DREAM	Disaster Risk and Exposure Assessment for Mitigation [Program]
DRRM	Disaster Risk Reduction and Management
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVBC	Data Validation and Bathymetry Component
FMC	Flood Modeling Component
FOV	Field of View
GiA	Grants-in-Aid
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HC	High Chord
IDW	Inverse Distance Weighted [interpolation method]
IMU	Inertial Measurement Unit
kts	knots
LAS	LiDAR Data Exchange File format
LC	Low Chord
LGU	local government unit
LiDAR	Light Detection and Ranging
LMS	LiDAR Mapping Suite
m AGL	meters Above Ground Level
MMS	Mobile Mapping Suite
MSL	mean sea level
NAMRIA	National Mapping and Resource Information Authority
NSTC	Northern Subtropical Convergence
PAF	Philippine Air Force
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
PDOP	Positional Dilution of Precision
PPK	Post-Processed Kinematic [technique]
PRF	Pulse Repetition Frequency
PTM	Philippine Transverse Mercator
QC	Quality Check
QT	Quick Terrain [Modeler]
RA	Research Associate
RIDF	Rainfall-Intensity-Duration-Frequency
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
SRS	Science Research Specialist
SSG	Special Service Group
TBC	Thermal Barrier Coatings
UPLB	University of the Philippines Los Baños
UP-TCAGP	University of the Philippines – Training Center for Applied Geodesy and Photogrammetry
UTM	Universal Transverse Mercator
WGS	World Geodetic System
ADZU	Ateneo de Zamboanga University

CHAPTER 1: OVERVIEW OF THE PROGRAM AND TAGO RIVER

Enrico C. Paringit, Dr. Eng.,and Prof. Edwin R. Abucay, Ariel U. Glorioso

1.1 Background of the Phil-LIDAR 1 Program

The University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP-TCAGP) launched a research program entitled “Nationwide Hazard Mapping using LiDAR” or Phil-LiDAR 1, supported by the Department of Science and Technology (DOST) Grants-in-Aid (GiA) Program. The program was primarily aimed at acquiring a national elevation and resource dataset at sufficient resolution to produce information necessary to support the different phases of disaster management. Particularly, it targeted to operationalize the development of flood hazard models that would produce updated and detailed flood hazard maps for the major river systems in the country.

Also, the program was aimed at producing an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping, with 50 cm and 20 cm horizontal and vertical accuracies, respectively. These accuracies were achieved through the use of the state-of-the-art Light Detection and Ranging (LiDAR) airborne technology procured by the project through DOST.

The methods applied in this report are thoroughly described in a separate publication entitled “FLOOD MAPPING OF RIVERS IN THE PHILIPPINES USING AIRBORNE LIDAR: METHODS” (Paringit, et. Al. 2017).

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Los Baños (UPLB). UPLB is in charge of processing LiDAR data and conducting data validation reconnaissance, cross section, bathymetric survey, validation, river flow measurements, flood height and extent data gathering, flood modeling, and flood map generation for the 45 river basins in the MIMAROPA Region. The university is located in Los Baños in the province of Laguna.

1.2 Overview of the Mamburao River Basin

The Mamburao River Basin covers the Municipality of Mamburao in Occidental Mindoro. It also covers some portions of the municipalities of Paluan and Abra de Ilog in Occidental Mindoro and the Municipality of Puerto Galera in Oriental Mindoro.The DENR River Basin Control Office (RBCO) states that the Mamburao River Basin has a drainage area of 272 km² and an estimated 435 cubic meter (MCM) annual run-off (RBCO, 2015).

Mamburao River Basin is a 31,500-hectare watershed located in Occidental Mindoro. It covers the barangays of Balao, Cabacao, Lumangbayan, Poblacion, Tibag, Udalom Wawa, Armado and Santa Maria of Abra De Ilog municipality; and Balansay, Fatima, Payompon, San Luis, Talabaan, Tayamaan and Poblacion 1-8 of Mamburao municipality. The basin area has seven geological classifications including Paleocene-Eocene, Recent, Oligocene-Miocene and Oligocene types. The river basin is also generally characterized by >50% slope and elevation of 301 to 2,200 meters above mean sea level. Mamburao River Basin has eight soil types: San Manuel clay loam, Alaminos silty clay loam, San Manuel sandy loam, Quiangua clay loam, San Manuel loamy sand, Quiangua silt loam, San Manuel silt, and San Manuel silt Loam. Unclassified soil (rough mountainous land.) and beach sand can also be found in the area. Cultivated area mixed with brushland/grassland is the most dominant land cover along with built-up areas, crop land mixed with coconut plantation, and grasslands.

Climate Type I and III prevails in MIMAROPA and Laguna based on the Modified Corona Classification of climate. Type I has two pronounced seasons, dry from November to April, and wet the rest of the year with maximum rain period from June to September. On the other hand, Type III has no very pronounced maximum rain period and with short dry season lasting only from one to three months, during the period from December to February or from March to May.

Mamburao River passes through Balansay, Payompon, Poblacion 5-8, San Luis and Tangkalan in Mamburao municipality; and Armado and Cabacao in Abra De Ilog municipality. The 2010 NSO Census of Population and Housing showed that the most populated barangays are Payompon in Mamburao and Cabacao in Abra De Ilog.

Its main stem, Mamburao River, is among the forty-five (45) river systems in Occidental Mindoro. According to the 2015 national census of PSA, a total of 25,148 persons are residing within the immediate vicinity of the river, which is distributed among barangays Tayamaan, San Luis (Ligang), Payompon, Poblacion 5, Poblacion 6, Poblacion 7, and Poblacion 8 in the Municipality of Mamburao. The economy of Occidental Mindoro Province rests on livestock and agriculture with rice, corn, and coconut as the main crops and products (Philippine Statistics Authority, 2017). Last September 23, 2013, flood due to southwest monsoon rains hits 3 municipalities in Occidental Mindoro, namely Abra de Ilog, Sablayan and Mamburao. Heavy rains affected 516 families (2,014 persons) according to MIMAROPA DRRMC (Virola M., Cinco M., 2013).

Based on the studies conducted by the Mines and Geosciences Bureau, only barangay Cabacao in Abra de Ilog is free from flooding. Barangays Payomon, Poblacion 5, Poblacion 6, Poblacion 7, Poblacion 8, San Luis, and Armando are noted to have moderate to high flood susceptibility while Brgy. Balansay has the highest concern as it is known to be the most prone to flooding. The field surveys conducted by the PHIL-LiDAR 1 validation team found that a number of notable weather disturbance caused flooding in 2008 (Frank), 2009 (Ondoy), 2013 (Yolanda), 2014 (Ruby), 2015 (Nona) and 2016 (Nina). Heavy rains brought by southwest monsoon also caused flooding in 2014 affecting Barangay 2 and Alakaap

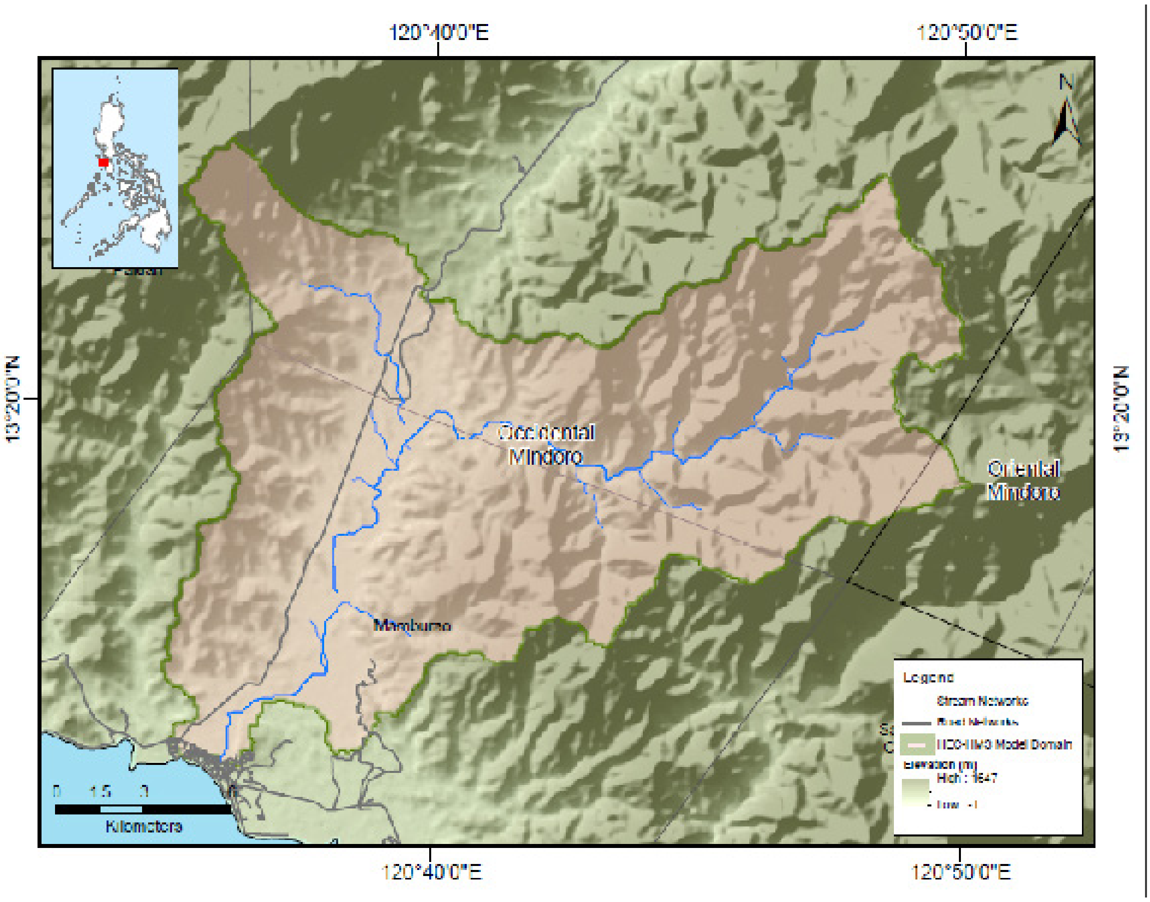

Figure 1. Map of the Tago River Basin (in brown)

CHAPTER 2: LIDAR DATA ACQUISITION OF THE MAMBURAO FLOODPLAIN

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The methods applied in this Chapter were based on the DREAM methods manual (Sarmiento, et al., 2014) and further enhanced and updated in Paringit, et al. (2017).

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Mamburao floodplain in Occidental Mindoro province. These missions were planned for 20 lines that run for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the Aquarius and Pegasus LiDAR systems used are found in Table 1 and Table 2, respectively. Figure 2 shows the flight plan for Mamburao floodplain. Annex 1 shows the technical specification of the Aquarius and Pegasus LiDAR systems and the aerial camera.

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Table 1. Flight planning parameters for Aquarius LiDAR system

Block Name	Flying Height (m AGL)	Overlap (%)	Max Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK29L	700	30	30	50	40	110	5
BLK29O	600	30	40/36	50	40	110	5
BLK29M	600	30	36	50	40	110	5
BLK29M	300/400	30	40	33/50	40	110	5

Table 2. Flight planning parameters for Pegasus LiDAR system

Block Name	Flying Height (m AGL)	Overlap (%)	Max Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
BLK29A	1400	30	40	150	30	115	5
BLK29B	1200	30	50	200	30	115	5
BLK29C	1200	30	50	200	30	115	5
BLK29D	1400	30	40	150	30	115	5
BLK29E	1400	30	40	150	30	115	5

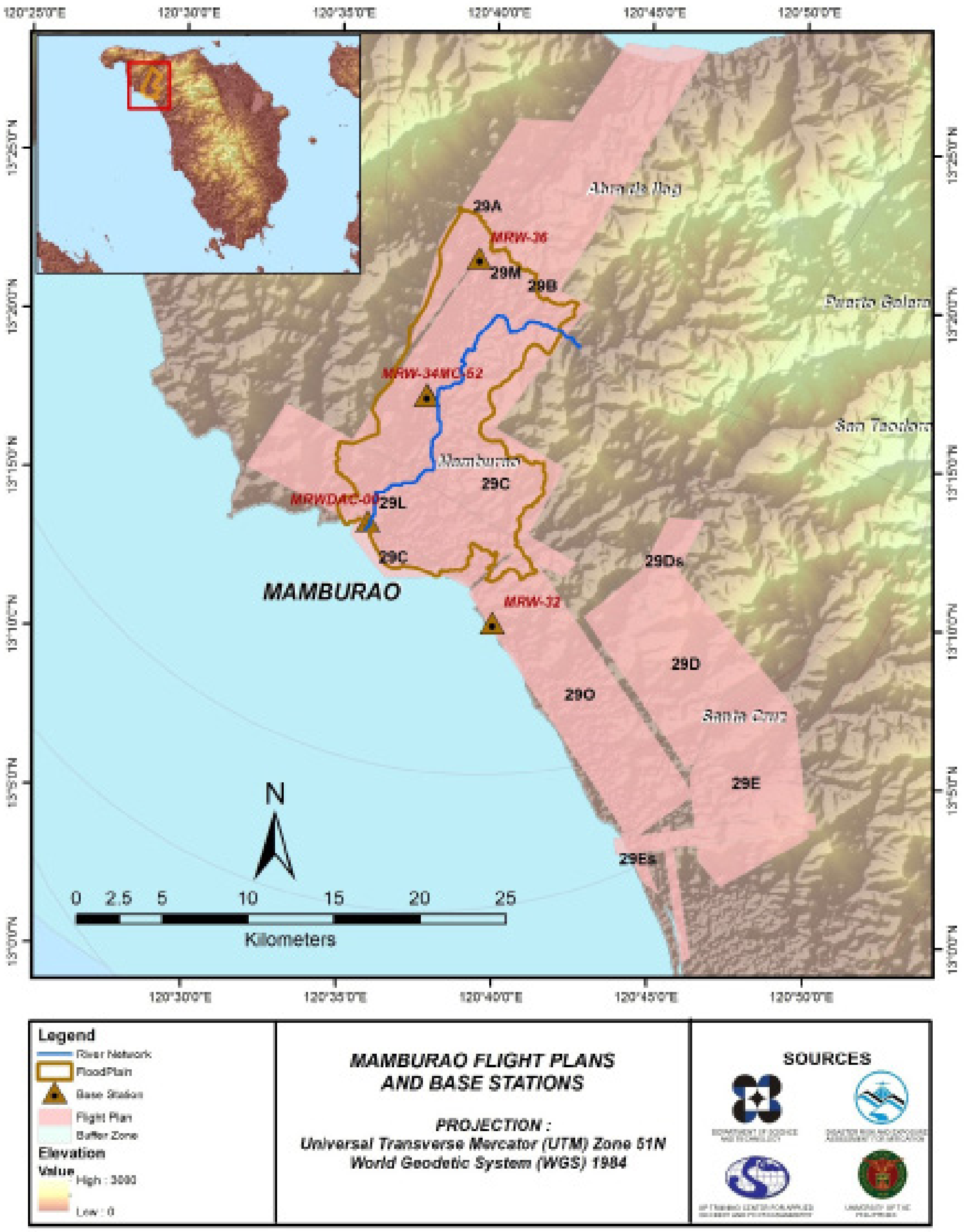

Figure 2. Flight plans and base stations used for Mamburao Floodplain survey

2.2 Ground Base Station

Four (4) NAMRIA ground control points (GCP): MRW-32, MRW-34, MRW-36, and MRW-30 which are all of second (2nd) order accuracy were recovered for use as base station during the survey. A benchmark: MC-52 was also recovered for vertical reference. Also, MRWDAC-00 was established as 2nd order control point for the project's accuracy as back-up base station during flight. The certifications for the NAMRIA reference points are found in Annex A-2 while the baseline processing reports are found in Annex A-3. These were used as base stations or reference points during flight operations for the entire duration of the survey (February 19, 20, 22, 2014 and December 6-8, 2015). Base stations were observed using dual frequency GPS receivers, TRIMBLE SPS 852, SPS 882, and SPS 985. Flight plans and location of base stations used during the aerial LiDAR acquisition in Mamburao floodplain are shown in Figure 2.

Figure 3 to Figure 8 show the recovered NAMRIA reference points within the area, while Table 2 to Table 8 show the corresponding details about the following NAMRIA control stations and established points. In addition, Table 9 shows the list of all ground control points occupied in line with their respective mission names and flight numbers, together with the dates of acquisition.

(a)

(b)

Figure 3. a) MRW-30 as recovered in Amnay Bridge in Brgy. Pinagturilan, municipality of Sta. Cruz, Occidental Mindoro. b) NAMRIA reference point MRW-30 as recovered by the field team.

Table 3. Details of the recovered NAMRIA horizontal control point MRW-30 used as base station for the LiDAR data

Station Name	MRW-30	
Order of Accuracy	2^{nd} Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	12° 57’ 32.22950” N 120° 53’ 28.50896” E 42.01300 m
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 3 PRS 92)	Easting Northing	488,201.05 m 1,433,011.7 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	12° 57’ 27.19115” N 120° 53’ 33.54442” E 89.79300 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	271,237.33 m 1,433,451.97 m

(b)

Figure 4. a) MRW-32 as recovered in the corner of a day care center in Brgy. Fatima, municipality of Mamburao, Occidental Mindoro. b) NAMRIA reference point MRW-32 as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point MRW-32 used as base station for the LiDAR data acquisition.

Station Name	MRW-32	
Order of Accuracy	2^{nd} Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 10’ 14.92094” N 120° 39’ 52.29557” E 1.47400 m
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 3 PRS 92)	Easting Northing	463,632.46 m 1,456,469.064 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 10’ 9.81293” N 120° 39’ 57.31386” E 48.13600 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	246,845.90 m 1,457,111.12 m

(b)

Figure 5. a) MRW-34 as recovered in Balibago Bridge in Brgy. Armado,municipality of Abra de Ilog, Occidental Mindoro. b) NAMRIA reference point MRW-34 as recovered by the field team.

Table 5. Details of the recovered NAMRIA horizontal control point MRW-34 used as base station for the LiDAR data acquisition.

Station Name	MRW-34	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 17’ 25.00981” N 120° 37’ 41.53630” E 8.01600 m
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 3 PRS 92)	Easting Northing	459,714.493 m 1,469,690.588 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 17’ 19.87026” N 459,714.493 m 1,469,690.588 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	243,032.08 m 1,470,369.33 m

(b)

Figure 6. a) MRW-36 as recovered in Baclaran Bridge in Brgy. Cabacao, municipality of Abra de Ilog, Occidental Mindoro. b) NAMRIA reference point MRW-36 as recovered by the field team.

Table 6. Details of the recovered NAMRIA horizontal control point MRW-36 used as base station for the LiDAR data acquisition

Station Name	MRW-36	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 21' 44.07349" North 120° 39' 20.54160" East 31.49300 m
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 3 PRS 92)	Easting Northing	462,705.446 m 1,477,646.985 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 21' 38.91908" North 120° 39' 25.54340" East 77.62100 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	246,088.34 m 1,478,304.87 m

Figure 7. MRWDAC-00 as established in Mamburao, Occidental Mindoro

Table 7. Details of the horizontal control point MRWDAC-00 used as base station for the LiDAR Acquisition with the processed coordinates.

Station Name	MRWDAC-00	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	13° 13' 23.10495" N 120° 35' 55.10572" E 11.629 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 13' 17.97899" N 120° 36' 00.11980" E 57.99 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	239,755.83 m 1,462,963.504 m

(b)

Figure 6.a) MC-52 as recovered in Balibago Bridge in Brgy. Armado, municipality of Abra de Ilog, Occidental Mindoro. b) NAMRIA reference point MC-52 as recovered by the field team

Table 8. Details of the recovered NAMRIA horizontal control point MC-52 used as base station for the LiDAR data acquisition.

Station Name	MC-52	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 20,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude	13° 17’ 25.66996” N 120° 37’ 41.97783” E
Grid Coordinates, Philippine Transverse Mercator Zone 3 (PTM Zone 3 PRS 92)	Easting Northing	242,955.61 m 1,470,904.34 m
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	13° 17’ 20.53041” N 120° 37’ 46.98588” E 54.352 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting Northing	243,198.172 m 1,470,321.018 m
Mean Sea Level (MSL)	Elevation	9.0283 m

Table 9. Ground control points used during LiDAR data acquisition.

Date Surveyed	Flight Number	Mission Name	Ground Control Points
February 19, 2014	1120A	3BLK29L50A	MRW-32 & MRW-34
February 19, 2014	1122A	3BLK29O50B	MRW-32 & MRW-34
February 20, 2014	1124A	3BLK29OS51A	MRW-32 & MRW-34
February 20, 2014	1126A	3BLK29M51B	MRW-36 & MC-52
February 22, 2014	1134A	3BLK29MS53B	MRW-32 & MRW-34
December 6, 2015	3058P	1BLK29C340A	MRW-34 & MC-52
December 7, 2015	3062P	1BLK29BCS341A	MRW-34 & MC-52
December 8, 2015	3066P	1BLK29BCS341A	MRW-30 & MRWDAC-00

2.3 Flight Missions

Eight (8) missions were conducted to complete LiDAR data acquisition in Mamburao Floodplain, for a total of twenty-six hours and twenty-eight minutes (26+28) of flying time for RP-C9122. All missions were acquired using Aquarius and Pegasus LiDAR systems. The team line-up is shown in Annex A-4. The aerial camera (D-8900) was also used during the surveys. Table 10 shows the total area of actual coverage and number of images; and the corresponding flying hours per mission, while Table 11 presents the actual parameters used during the LiDAR data acquisition. The data transfer sheet, flight logs and flight status reports of each mission are shown in Annex 5, 6 and 7 respectively.

Table 10. Flight missions for LiDAR data acquisition in Mamburao floodplain.

Date Surveyed	Flight Number	Flight Plan Area (km²)	Surveyed Area (km²)	Area Surveyed within the Floodplain (km²)	Area Surveyed Outside the Floodplain (km²)	No. of Images (Frames)	Flying Hours	
							Hr	Min
19-Feb-14	1120A	70.77	93.739	48.953	44.786	1050	4	17
19-Feb-14	1122A	77.523	23.383	0.439	22.944	300	2	17
20-Feb-14	1124A	77.523	91.211	3.525	87.686	1107	4	35
20-Feb-14	1126A	89.166	107.69	51.709	55.981	1269	4	5
22-Feb-14	1134A	89.166	25.301	17.3	8.001	512	2	59
6-Dec-15	3058P	38.589	67.098	43.068	24.03	150	2	5
7-Dec-15	3062P	169.896	174.845	55.111	119.734	391	3	23
8-Dec-15	3066P	122.932	115.297	26.781	88.516	245	2	47
TOTAL		735.565	698.564	246.886	451.678	5024	26	28

Table 11. Actual parameters used during LiDAR data acquisition

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (kHz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
1120A	700	30	30	50	40	110	5
1122A	700/600	30	30/40	50	40	110	5
1124A	600	30	36	50	40	110	5
1126A	600	30	36	50	40	110	5
1134A	600/550	30	36/40	50/70	40	110	5
3058P	1150	30	50	200	30	115	5
3062P	1400	30	40	150	30	115	5
3066P	1100/1400	30	50/40	200/150	30	115	5

2.4 Survey Coverage

Mamburao floodplain is located in the province of Occidental Mindoro situated within the municipality of Mamburao and portion of Abra de Ilog municipality. LiDAR swath coverage for these flights also cover parts of Paluan and Santa Cruz municipalities. The list of municipalities and/or cities surveyed, with at least one (1) square kilometer coverage is shown in Table 12. The actual coverage of the LiDAR acquisition for Mamburao Floodplain is presented in Figure 9.

Table 12. List of municipalities and/or cities surveyed during Mamburao floodplain LiDAR survey.

Province	Municipality/City	Area of Municipality/City	Surveyed Area (km^2)	Percentage of Area Surveyed
Occidental Mindoro	Mamburao	344.981	221.996	64%
	Abra de Ilog	523.865	137.536	26%
	Santa Cruz	709.539	136.833	19%
	Paluan	557.78	4.425	1%
TOTAL		2136.17	500.79	23.44%

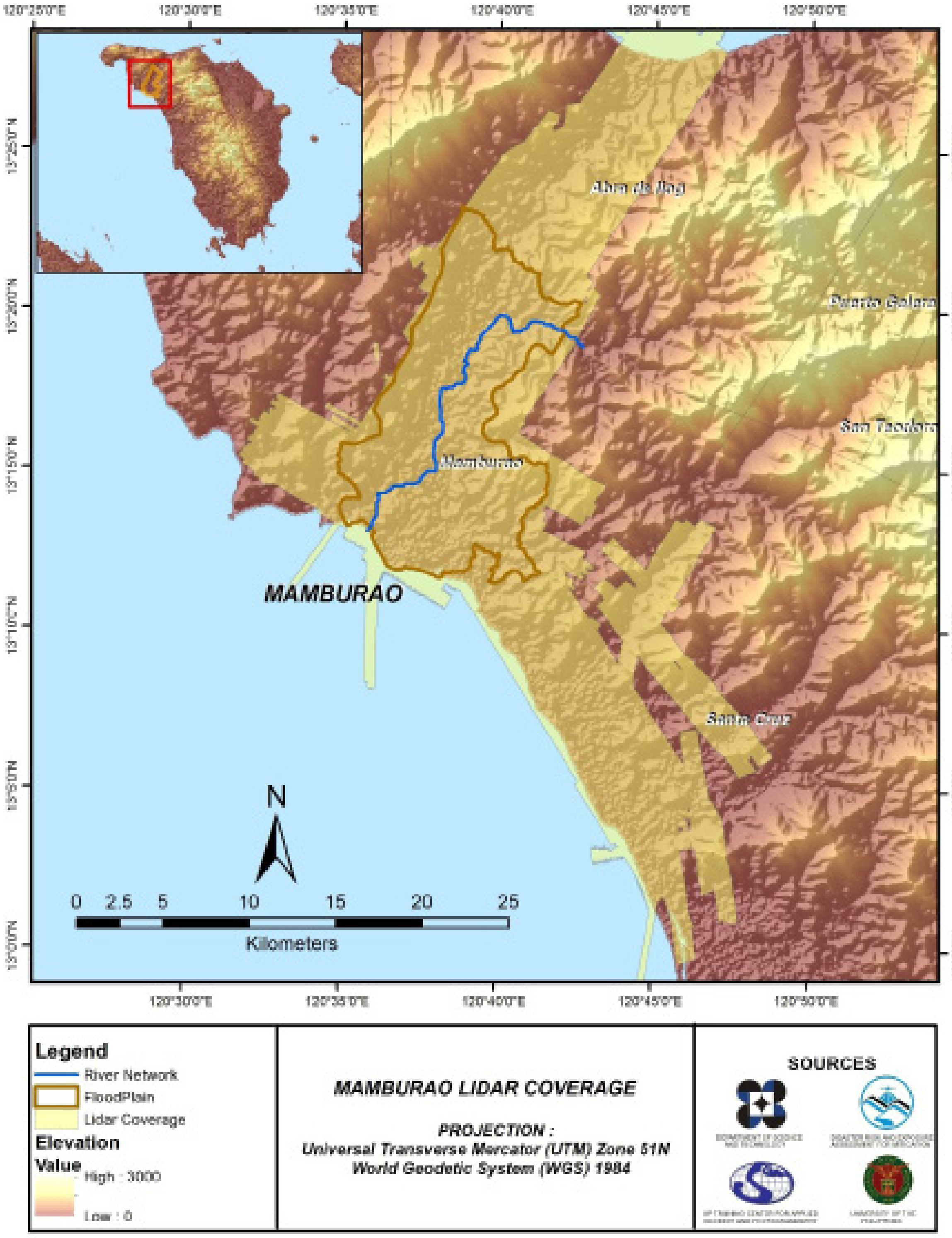

Figure 9. Actual LiDAR survey coverage for Mamburao floodplain

CHAPTER 3: LIDAR DATA PROCESSING FOR MAMBURAO FLOODPLAIN

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The methods applied in this chapter were based on the DREAM methods manual (Ang et al., 2014) and further enhanced and updated in Paringit et al. (2017).

3.1 LiDAR Data Processing for Mamburao Floodplain

3.1.1 Overview of the LiDAR Date Pre-Processing

The data transmitted by the Data Acquisition Component are checked for completeness based on the list of raw files required to proceed with the pre-processing of the LiDAR data. Upon acceptance of the LiDAR field data, georeferencing of the flight trajectory is done in order to obtain the exact location of the LiDAR sensor when the laser was shot. Point cloud georectification is performed to incorporate correct position and orientation for each point acquired. The georectified LiDAR point clouds are subject for quality checking to ensure that the required accuracies of the program, which are the minimum point density, vertical and horizontal accuracies, are met. The point clouds are then classified into various classes before generating Digital Elevation Models such as Digital Terrain Model and Digital Surface Model.

Using the elevation of points gathered in the field, the LiDAR-derived digital models are calibrated. Portions of the river that are barely penetrated by the LiDAR system are replaced by the actual river geometry measured from the field by the Data Validation and Bathymetry Component. LiDAR acquired temporally are then mosaicked to completely cover the target river systems in the Philippines. Orthorectification of images acquired simultaneously with the LiDAR data is done through the help of the georectified point clouds and the metadata containing the time the image was captured.

These processes are summarized in the flowchart shown in Figure 10.

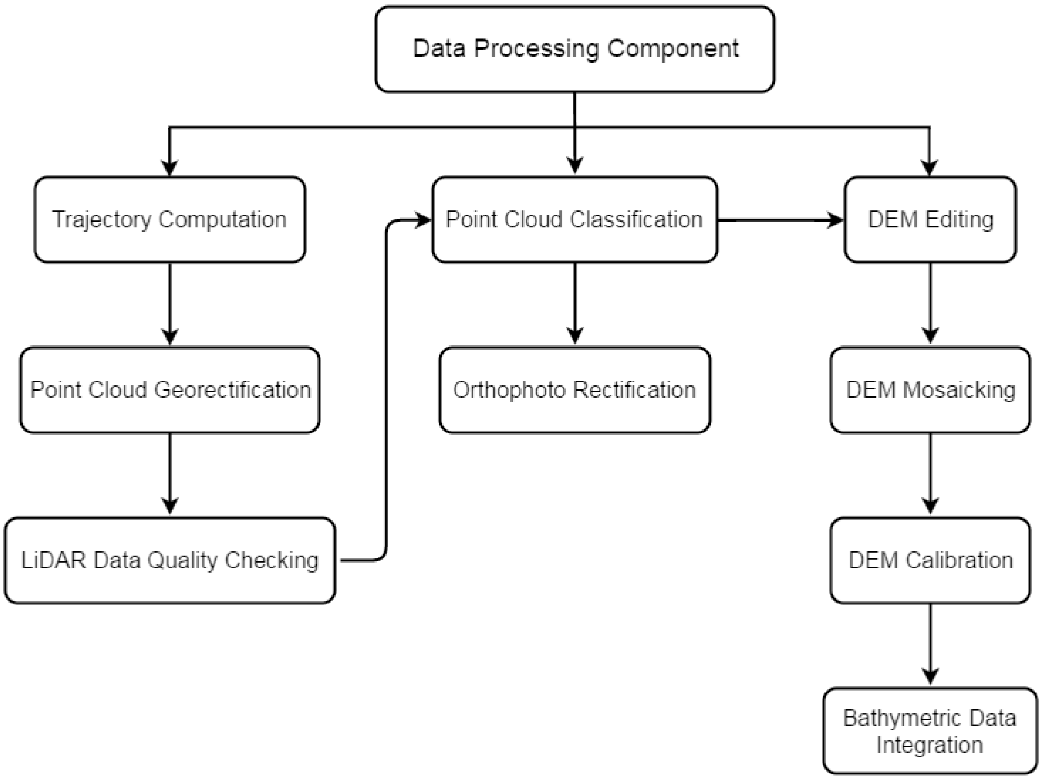

Figure 10.Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Mamburao floodplain can be found in Annex 5. Missions flown during the first survey conducted on February 2014 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Aquarius system while missions acquired during the last survey on December 2015 were flown using the Pegasus system over Occidental Mindoro. The Data Acquisition Component (DAC) transferred a total of 81.18 Gigabytes of Range data, 1.48 Gigabytes of POS data, 114.11 Megabytes of GPS base station data, and 327.49 Gigabytes of raw image data to the data server on February 19, 2014 for the first survey and December 8, 2015 for the last survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Mamburao was fully transferred on January 15, 2016, as indicated on the Data Transfer Sheets for Mamburao floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metric parameters of the computed trajectory for flight 1120A, one of the Mamburao flights, which is the North, East, and Down position RMSE values are shown in Figure 11. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on February 19, 2014 00:00AM. The y-axis is the RMSE value for that particular position.

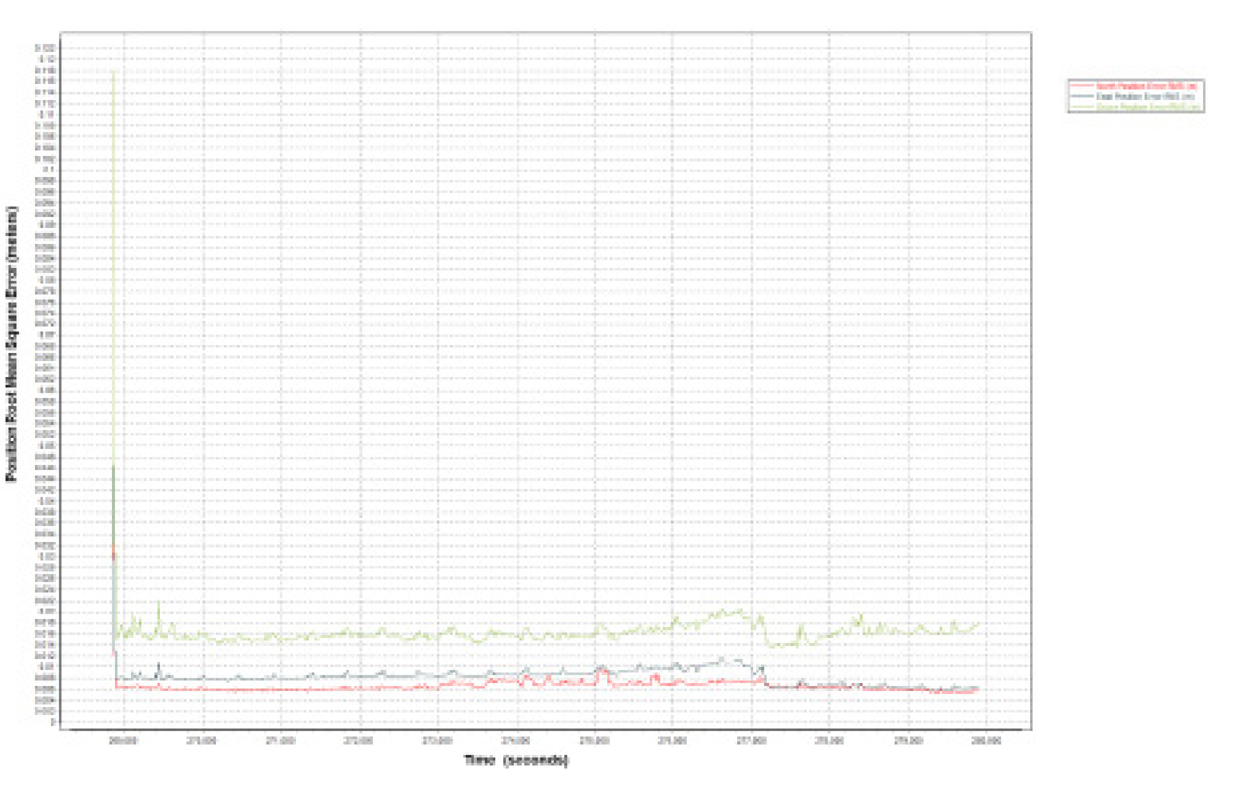

Figure 11. Smoothed Performance Metric Parameters of Mamburao Flight 1120A.

The time of flight was from 269000 seconds to 280000 seconds, which corresponds to morning of February 19, 2014. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft. Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 11 shows that the North position RMSE peaks at 1.00 centimeters, the East position RMSE peaks at 1.20 centimeters, and the Down position RMSE peaks at 2.20 centimeters, which are within the prescribed accuracies described in the methodology.

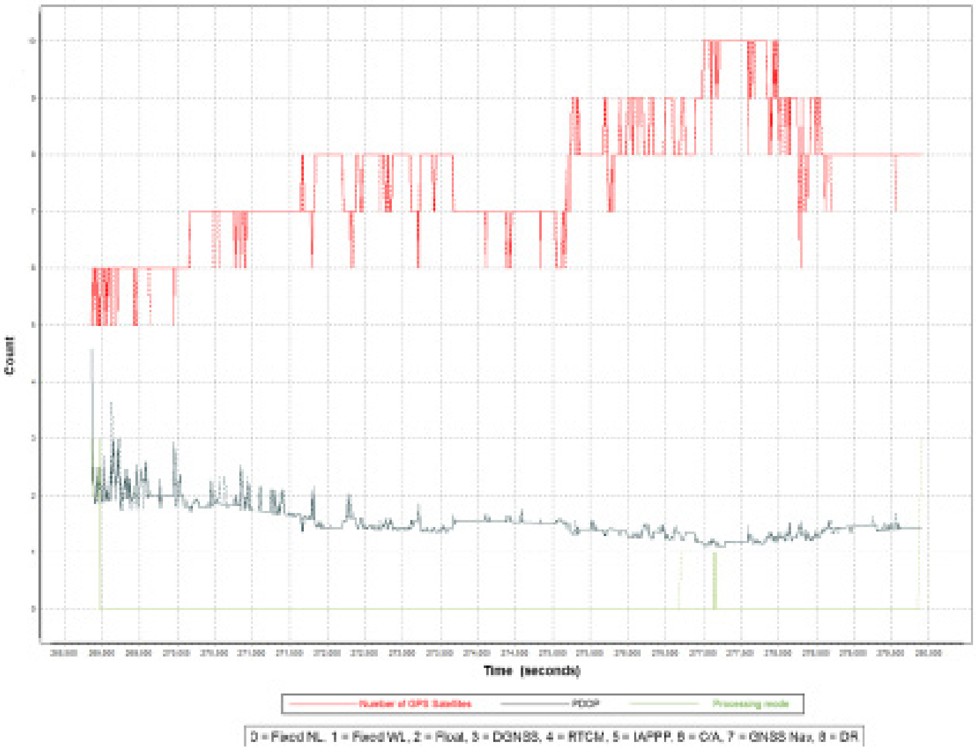

Figure 12. Solution Status Parameters of Mamburao Flight 1120A.

The Solution Status parameters of flight 1120A, one of the Mamburao flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 12. The graphs indicate that the number of satellites during the acquisition did not go below 6. Majority of the time, the number of satellites tracked was between 6 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Mamburao flights is shown in Figure 13.

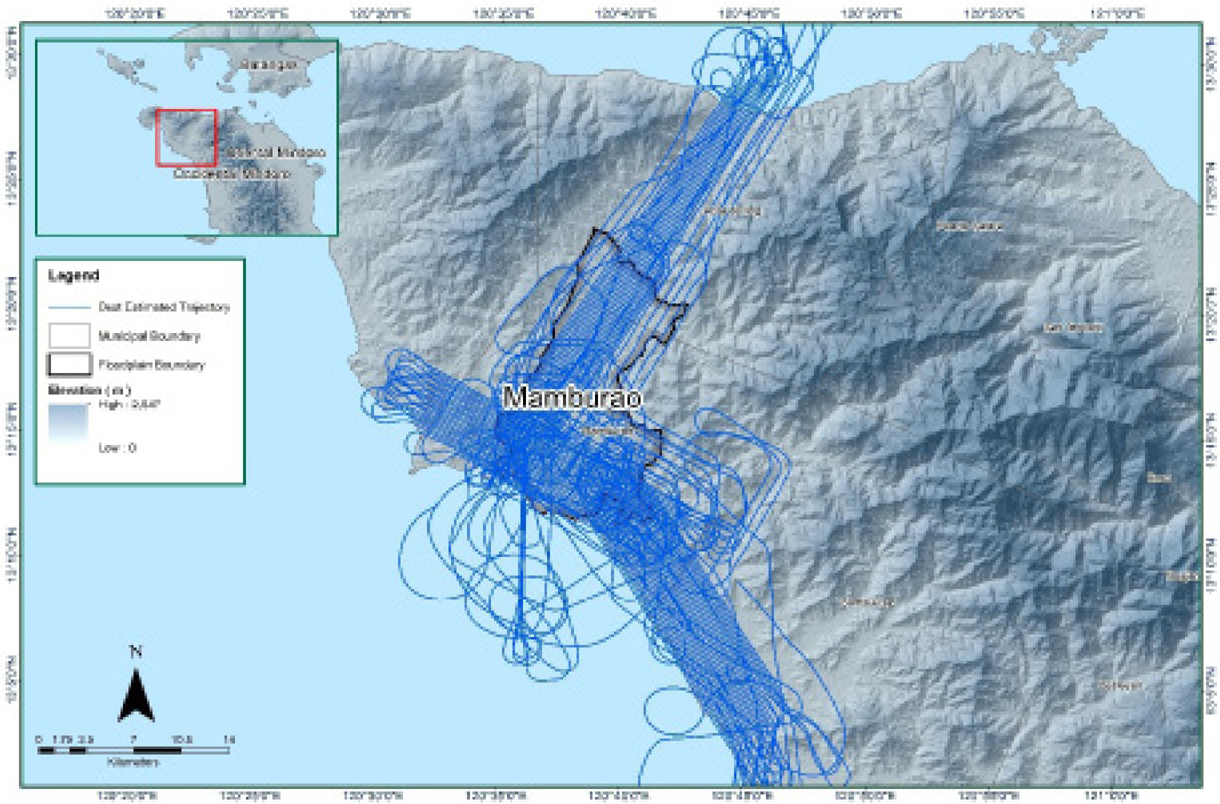

Figure 13. The best estimated trajectory of the LiDAR missions conducted over the Mamburao floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 93 flight lines, with each flight line containing one channel, since the Aquarius system contains one channel only. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Mamburao floodplain are given in Table 13.

Table 13. Self-Calibration Results values for Mamburao flights.

Parameter		Value
Boresight Correction stdev	(<0.001degrees)	0.000292
IMU Attitude Correction Roll and Pitch Corrections stdev	(<0.001degrees)	0.000966
GPS Position Z-correction stdev	(<0.01meters)	0.0084

The optimum accuracy values for all Mamburao flights were also calculated based on the computed standard deviations of the corrections of the orientation parameters. Standard deviation values for individual blocks are available in the Annex 8. Mission Summary Reports.

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Mamburao Floodplain is shown in Figure B-5. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

Figure 14. Boundary of the processed LiDAR data over Mamburao Floodplain

The total area covered by the Mamburao missions is 573.73 sq.km that is comprised of eight (8) flight acquisitions grouped and merged into nine (9) blocks as shown in Table 14.

Table 14. List of LiDAR blocks for Mamburao floodplain.

LiDAR Blocks	Flight Numbers	Area (sq.km)
OccidentalMindoro_Blk29L	1120A	88.68
OccidentalMindoro_Blk29M	1126A	114.69
	1134A	
OccidentalMindoro_Blk29O	1122A	102.35
	1124A	
OccidentalMindoro_reflights_Blk29L	3066P	61.53
OccidentalMindoro_reflights_Blk29L_additional	3062P	16.02
OccidentalMindoro_reflights_Blk29L_supplement	3066P	20.62
OccidentalMindoro_reflights_Blk29L_supplement2	3058P	18.05
OccidentalMindoro_reflights_Blk29M	3066P	32.18
OccidentalMindoro_reflights_Blk29M_additional	3062P	119.61
	TOTAL	**573.73 sq.km**

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 15. Since the Aquarius system employs one channel, we would expect an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines.

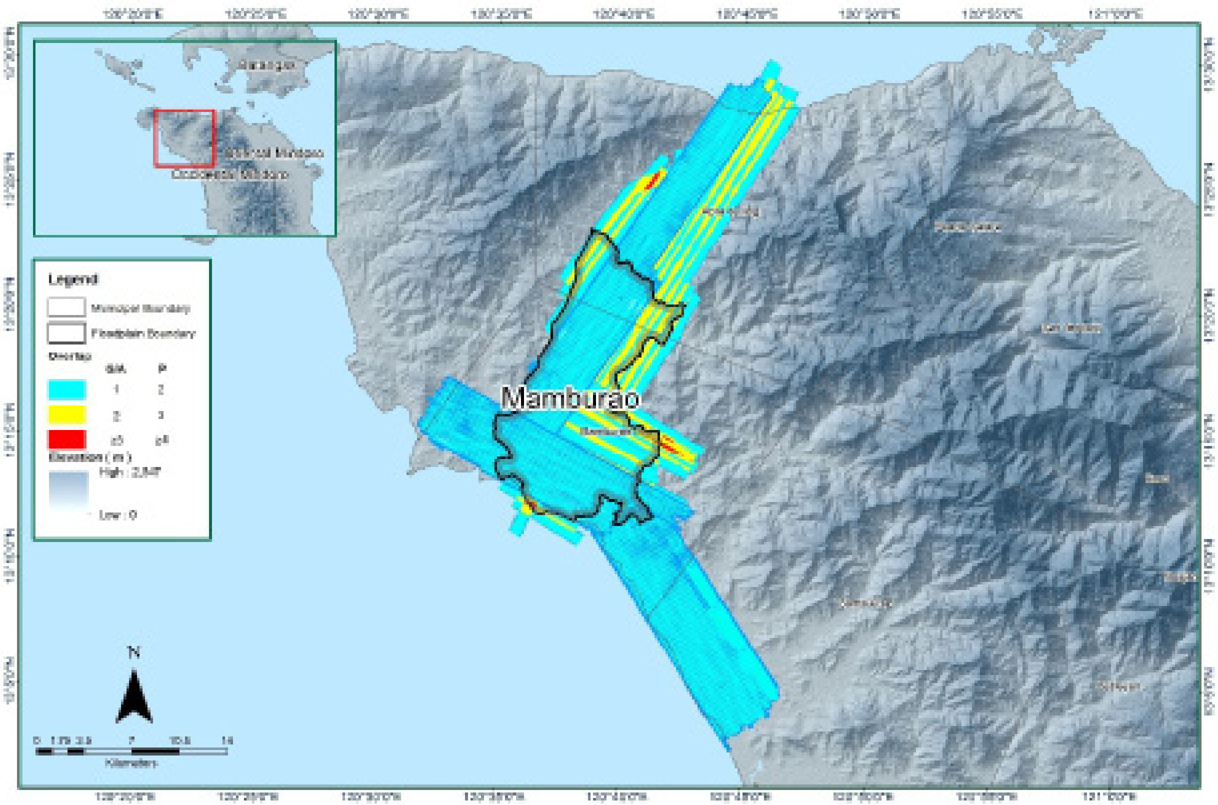

Figure 15. Image of data overlap for Mamburao floodplain.

The overlap statistics per block for the Mamburao floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the minimum and maximum percent overlaps are 25.19% and 47.26% respectively, which passed the 25% requirement.

The density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 16. It was determined that all LiDAR data for Mamburao floodplain satisfy the point density requirement, and the average density for the entire survey area is 3.00 points per square meter.

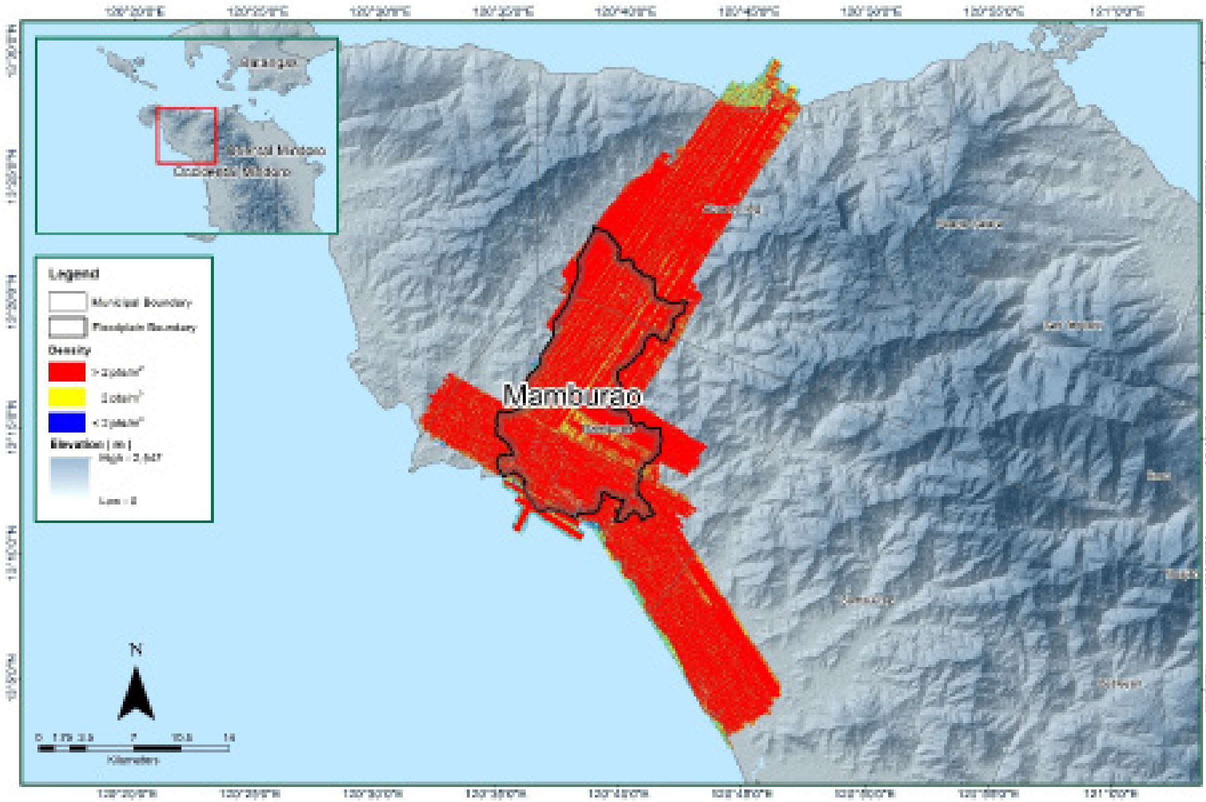

Figure 16. Density map of merged LiDAR data for Mamburao floodplain.

The elevation difference between overlaps of adjacent flight lines is shown in Figure 17. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

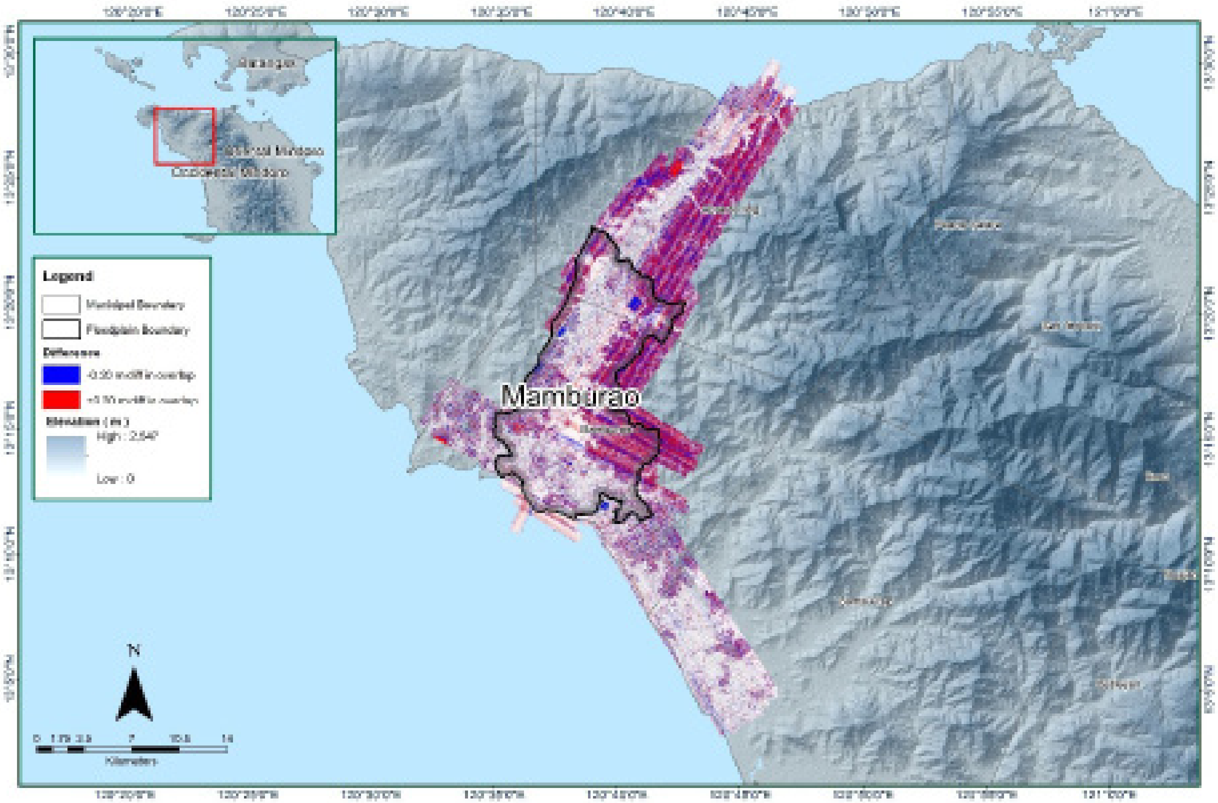

Figure 17. Elevation difference map between flight lines for Mamburao floodplain.

A screen capture of the processed LAS data from Mamburao flight 1120A loaded in QT Modeler is shown in Figure 18. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

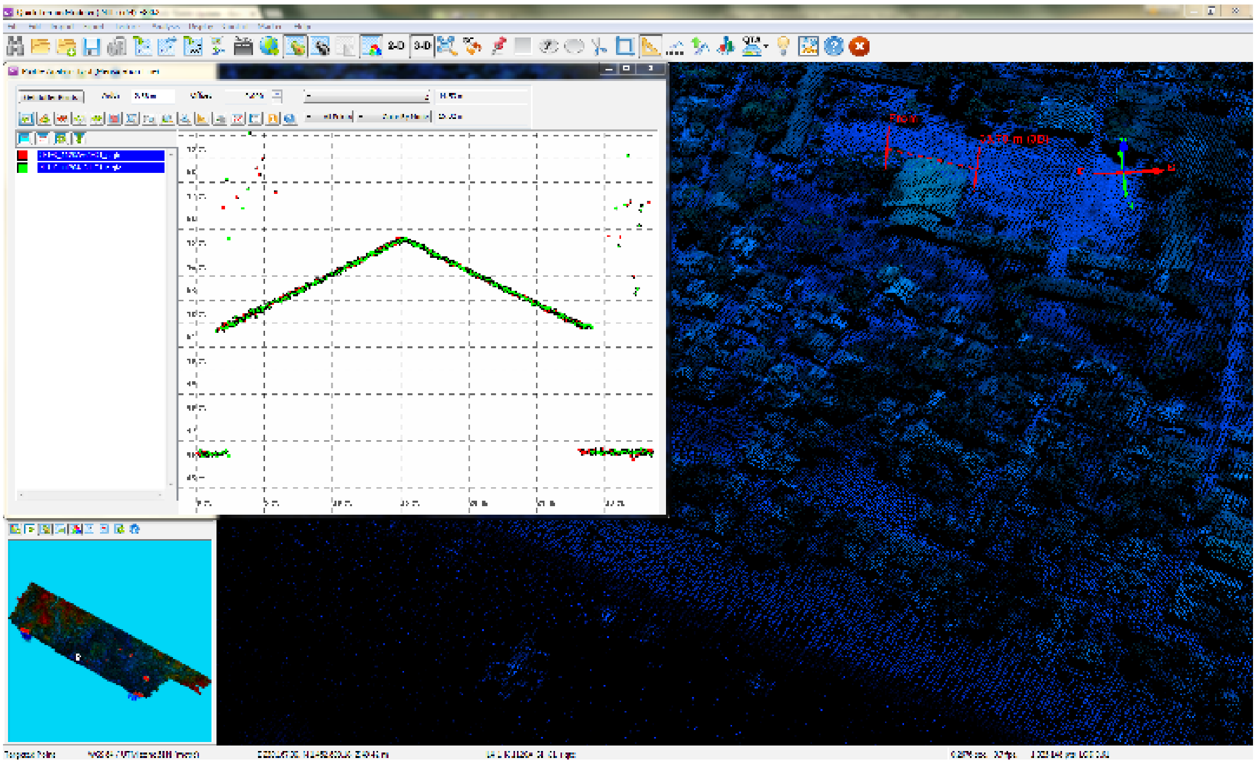

Figure 18. Quality checking for Mamburao flight 1120A using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 15. Mamburao classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	426,148,016
Low Vegetation	314,576,572
Medium Vegetation	524,622,843
High Vegetation	977,795,418
Building	102,679,714

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Mamburao floodplain is shown in Figure 19. A total of 879 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 15. The point cloud has a maximum and minimum height of 703.91 meters and 39.47 meters respectively.

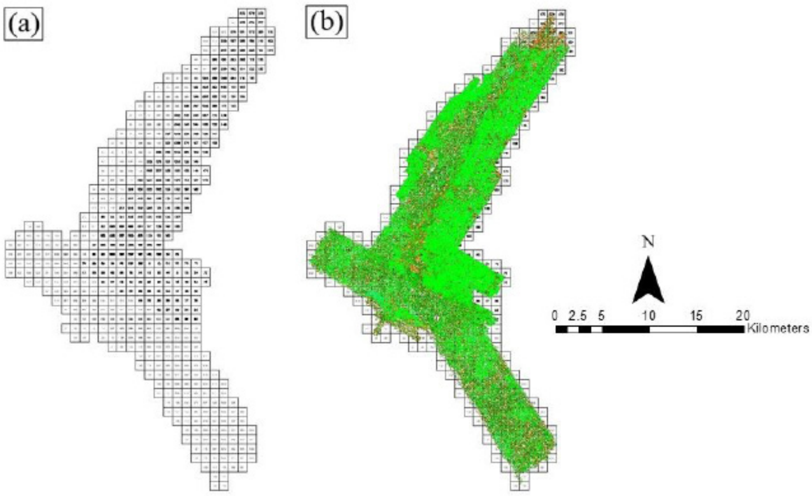

Figure 19. Tiles for Mamburao floodplain (a) and classification results (b) in TerraScan.

An isometric view of an area before and after running the classification routines is shown in Figure 20. The ground points are in orange, the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below canopy are classified correctly, due to the density of the LiDAR data.

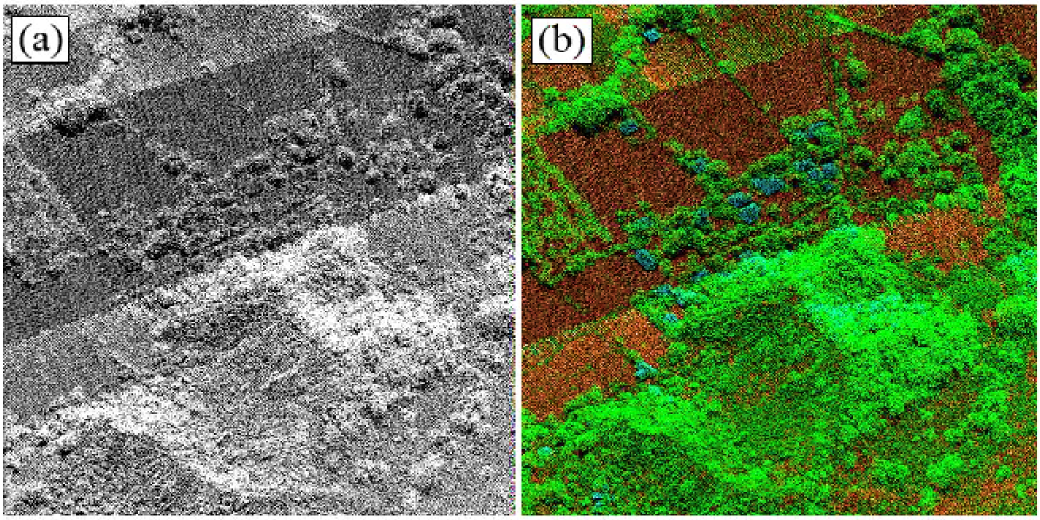

Figure 20. Point cloud before (a) and after (b) classification.

The production of last return (V_ASCII) and the secondary (T_ ASCII) DTM, first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are shown in Figure 21. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

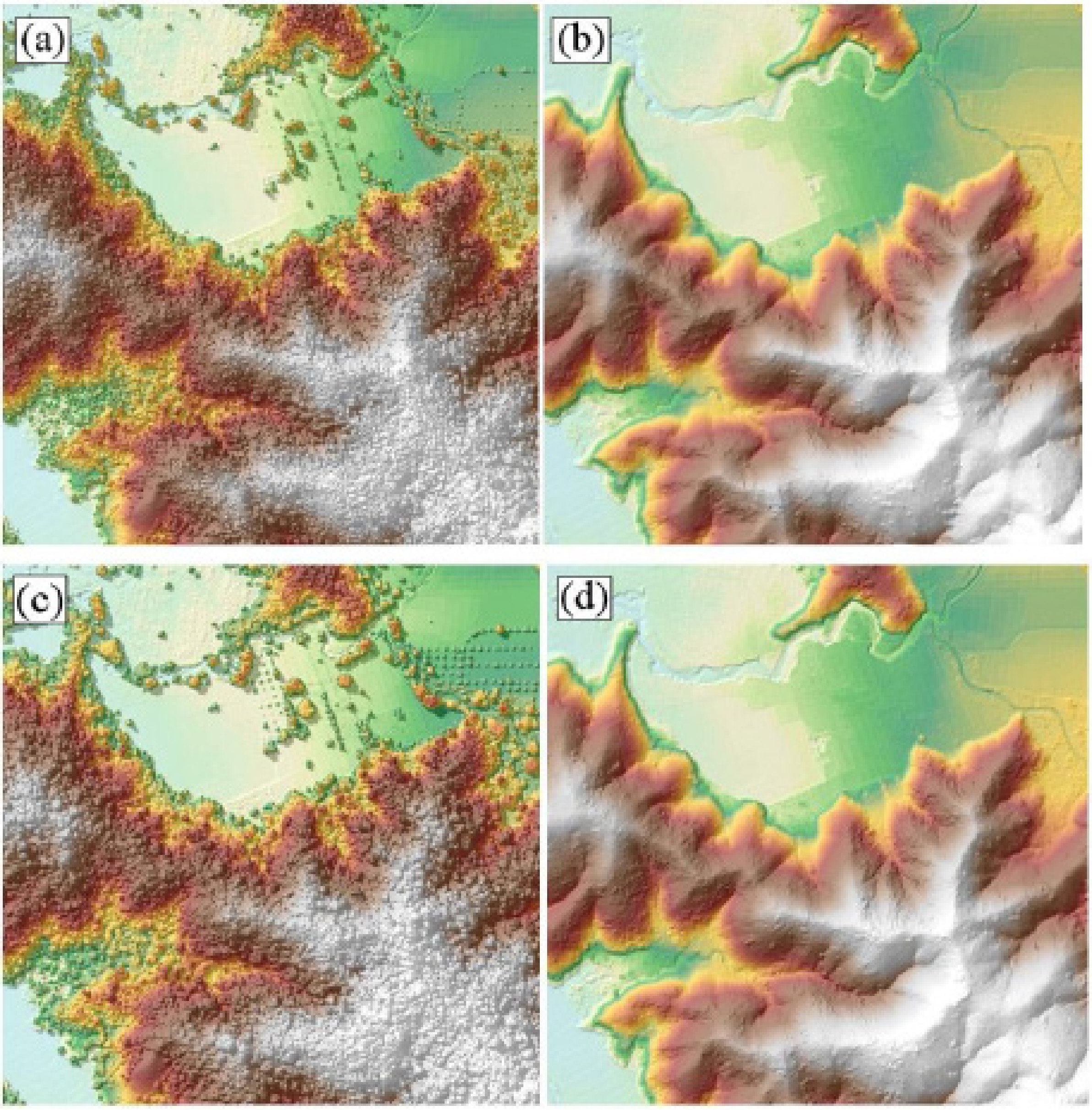

Figure 21. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Mamburao floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

The 723 1km by 1km tiles area covered by Mamburao floodplain is shown in Figure 22. After tie point selection to fix photo misalignments, color points were added to smoothen out visual inconsistencies along the seamlines where photos overlap. The Mamburao floodplain survey attained a total of 390.01 km2 in orthophotogaph coverage comprised of 3,103 images. A zoomed in version of sample orthophotographs named in reference to its tile number is shown in Figure 23.

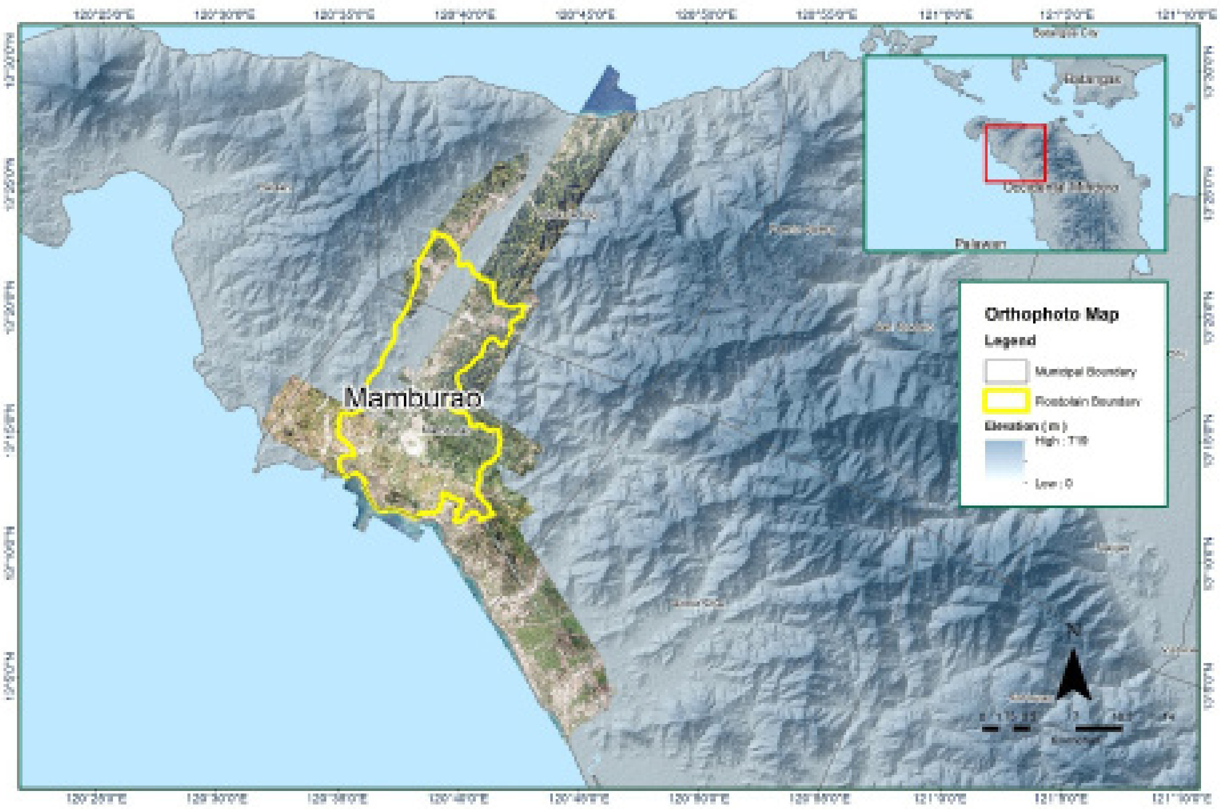

Figure 22. Mamburao floodplain with available orthophotographs.

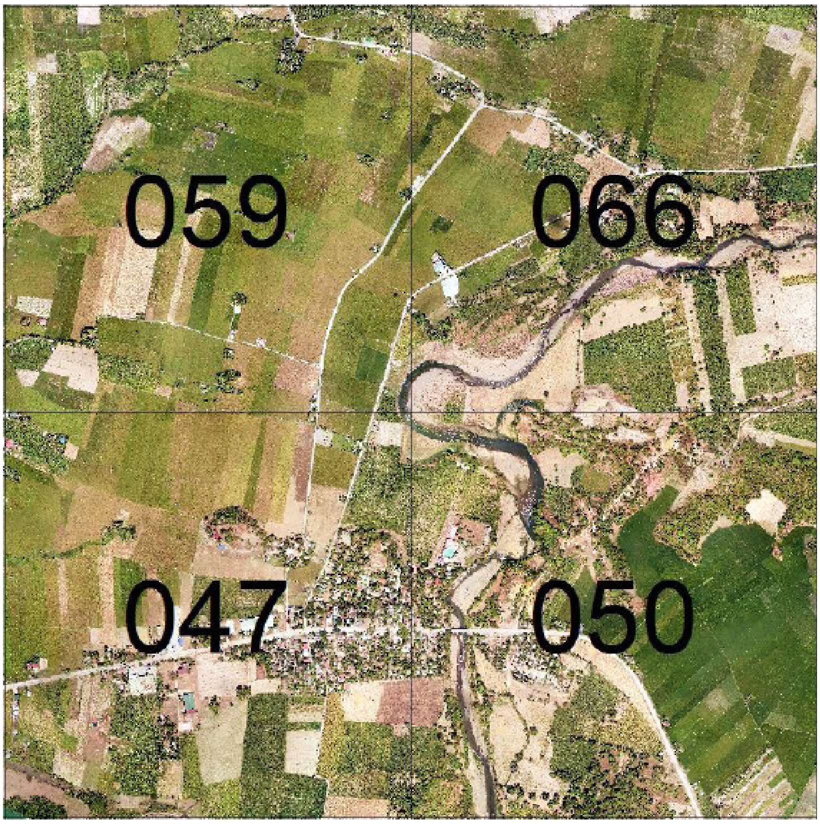

Figure 23. Sample orthophotograph tiles for Mamburao floodplain.

3.8 DEM Editing and Hydro-Correction

Nine (9) mission blocks were processed for Mamburao flood plain. These blocks are composed of Mindoro and Occidental_Mindoro_Reflight blocks with a total area of 573.73 square kilometers. Table 16 shows the name and corresponding area of each block in square kilometers.

Table 16. LiDAR blocks with its corresponding area

LiDAR Blocks	Area (sq.km)
OccidentalMindoro_Blk29L	88.68
OccidentalMindoro_Blk29M	114.69
OccidentalMindoro_Blk29O	102.35
OccidentalMindoro_reflight_Blk29L	61.53
OccidentalMindoro_reflight_Blk29L_additional	16.02
OccidentalMindoro_reflight_Blk29L_supplement	20.62
OccidentalMindoro_reflight_Blk29L_supplement2	18.05
OccidentalMindoro_reflight_Blk29M	32.18
OccidentalMindoro_reflight_Blk29M_additional	119.61
TOTAL	**573.73 sq.km**

Portions of DTM before and after manual editing are shown in Figure 24. The bridge (Figure 24a) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 24b) in order to hydrologically correct the river. The data gap (Figure 24c) has been filled to complete the surface (Figure 24d).

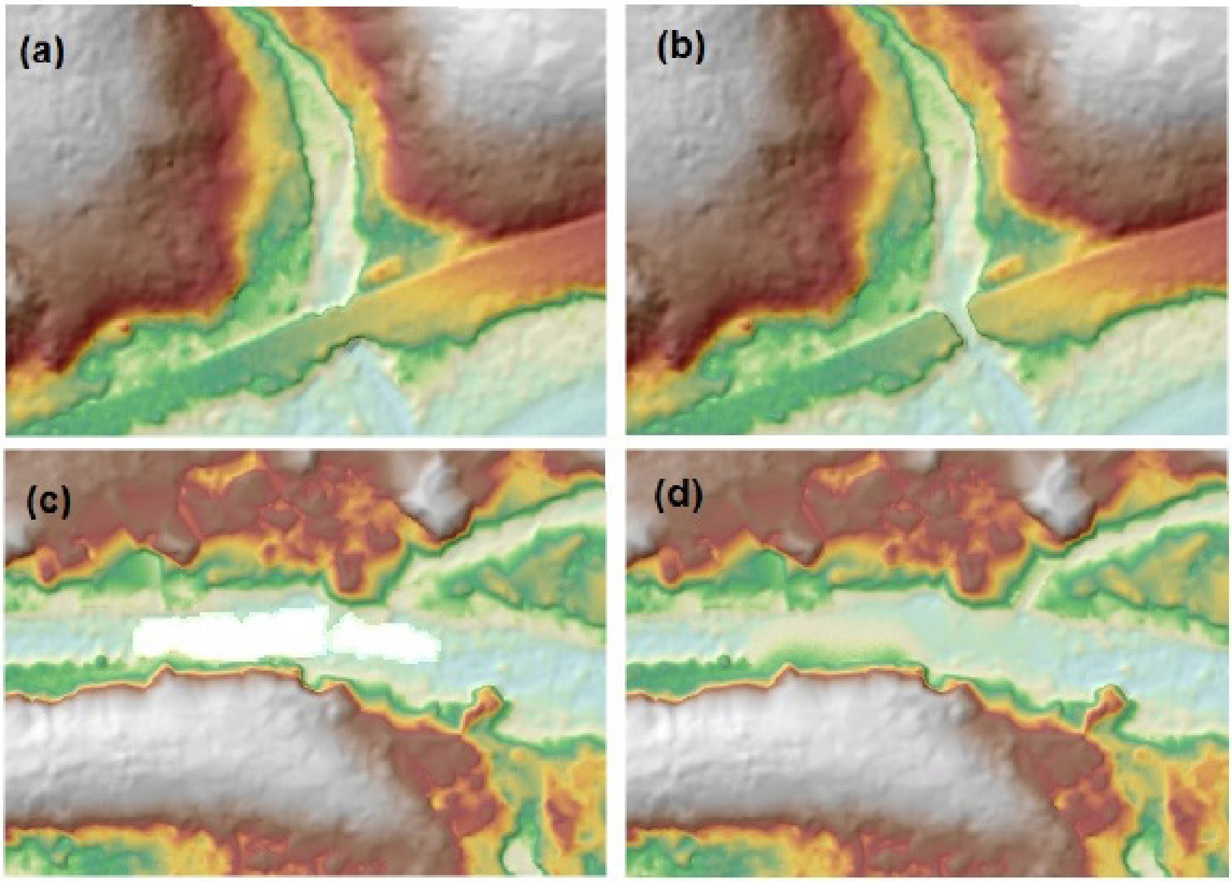

Figure 24. Portions in the DTM of Mamburao floodplain – a bridge before
(a) and after (b) manual editing; and data gaps before (c) and after (d) filling.

3.9 Mosaicking of Blocks

Mindoro_Blk29M was used as the reference block at the start of mosaicking because it was the first block mosaicked to the larger DTM of Mindoro. Upon inspection of the blocks mosaicked for the Mamburao floodplain, it was concluded that the elevation of the blocks needed adjustment before mosaicking. Table 17 shows the shift values applied to each LiDAR block during mosaicking.

Mosaicked LiDAR DTM for Mamburao floodplain is shown in Figure 25. It can be seen that the entire Mamburao floodplain is 100% covered by LiDAR data.

Table 17. Shift Values of each LiDAR Block of Mamburao floodplain

Mission Blocks	Shift Values (meters)		
	x	y	z
OccidentalMindoro_Blk29L	0.00	0.00	-0.22
OccidentalMindoro_Blk29M	0.00	0.00	0.00
OccidentalMindoro_Blk29O	0.00	0.00	-0.28
OccidentalMindoro_reflight_Blk29L	0.00	0.00	0.00
OccidentalMindoro_reflight_Blk29L_additional	0.00	0.00	-1.12
OccidentalMindoro_reflight_Blk29L_supplement	0.00	0.00	-0.9
OccidentalMindoro_reflight_Blk29L_supplement2	0.00	0.00	-1.02
OccidentalMindoro_reflight_Blk29M	0.00	0.00	-0.66
OccidentalMindoro_reflight_Blk29M_additional	0.00	0.00	0.00

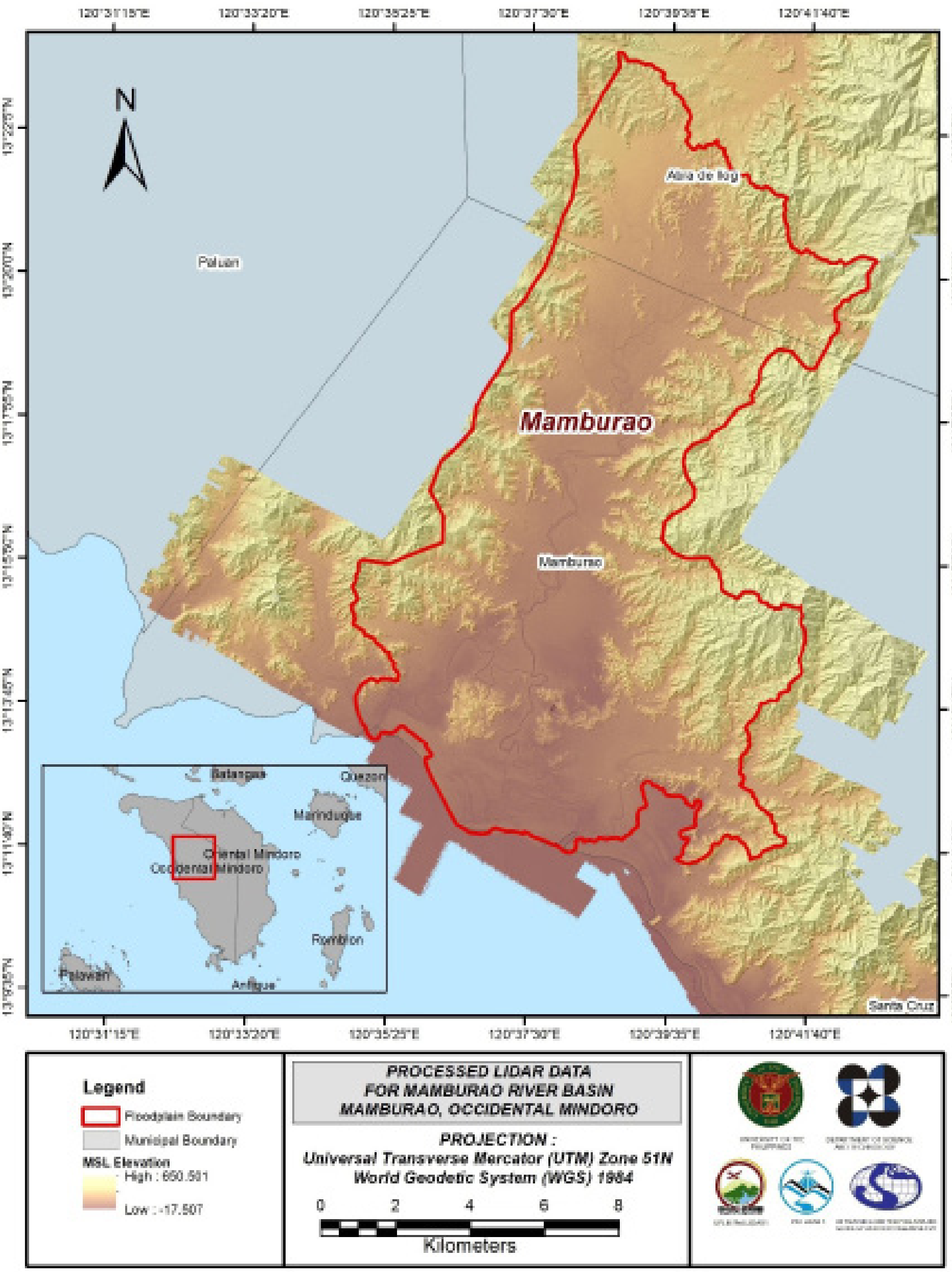

Figure 25. Map of Processed LiDAR Data for Mamburao Flood Plain.

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Mamburao to collect points with which the LiDAR dataset is validated is shown in Figure 26. A total of 18,538 survey points were used for calibration and validation of Occidental Mindoro LiDAR data. Random selection of 80% of the survey points, resulting to 14,831 points, were used for calibration. A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 27. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 0.18 meters with a standard deviation of 0.18 meters. Calibration of Mamburao LiDAR data was done by adding the height difference value, 0.18 meters, to Mamburao mosaicked LiDAR data. Table 18 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

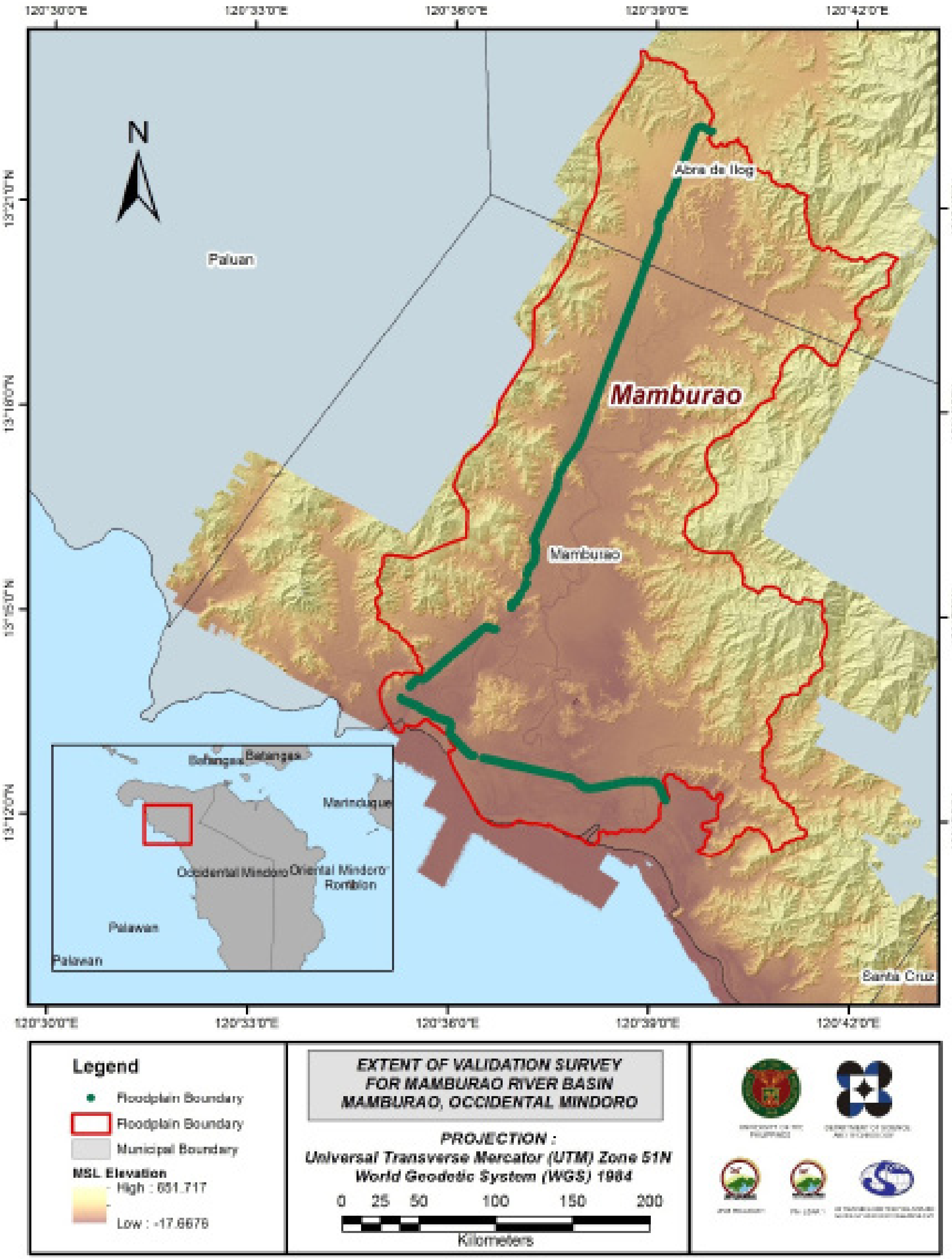

Figure 26. Map of Mamburao Flood Plain with validation survey points in green.

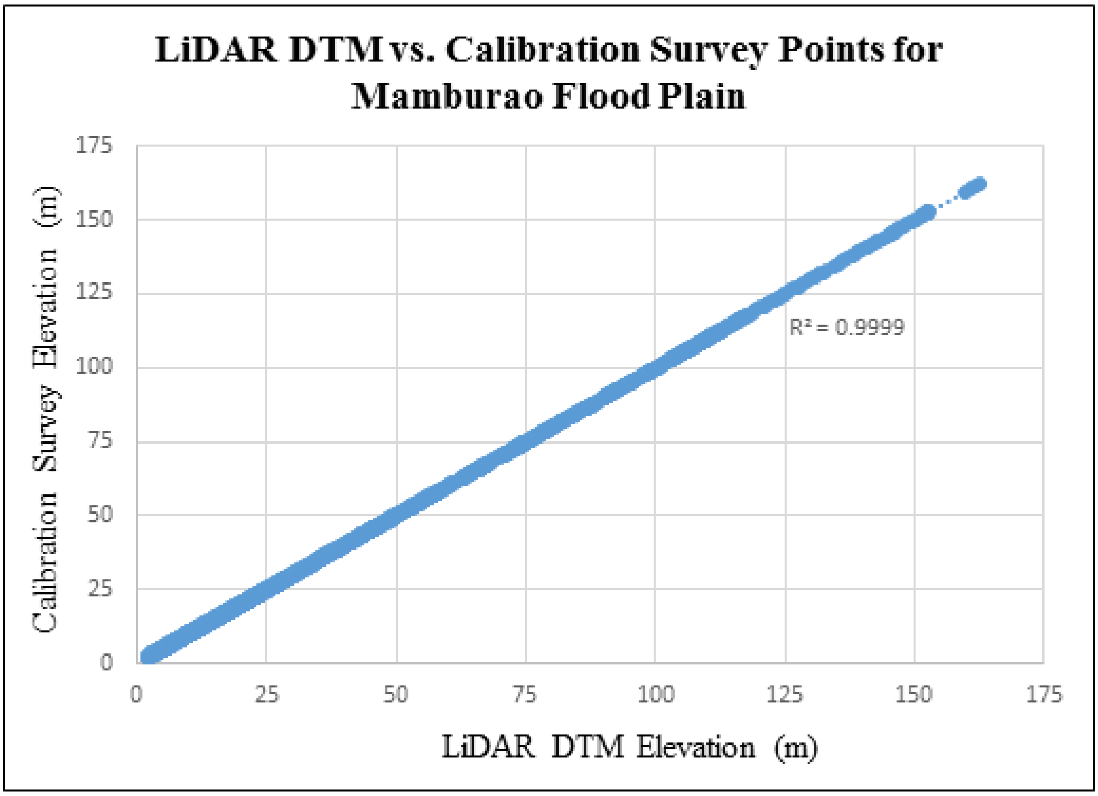

Figure 27. Correlation plot between calibration survey points and LiDAR data.

Table 18. Calibration Statistical Measures.

Calibration Statistical Measures	Value (meters)
Height Difference	0.18
Standard Deviation	0.18
Average	0.02
Minimum	-0.34
Maximum	0.38

A total of 2,785 survey points lie within Mamburao flood plain and were used for the validation of the calibrated Mamburao DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM is shown in Figure 28. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.71 meters with a standard deviation of 0.020 meters, as shown in Table 19.

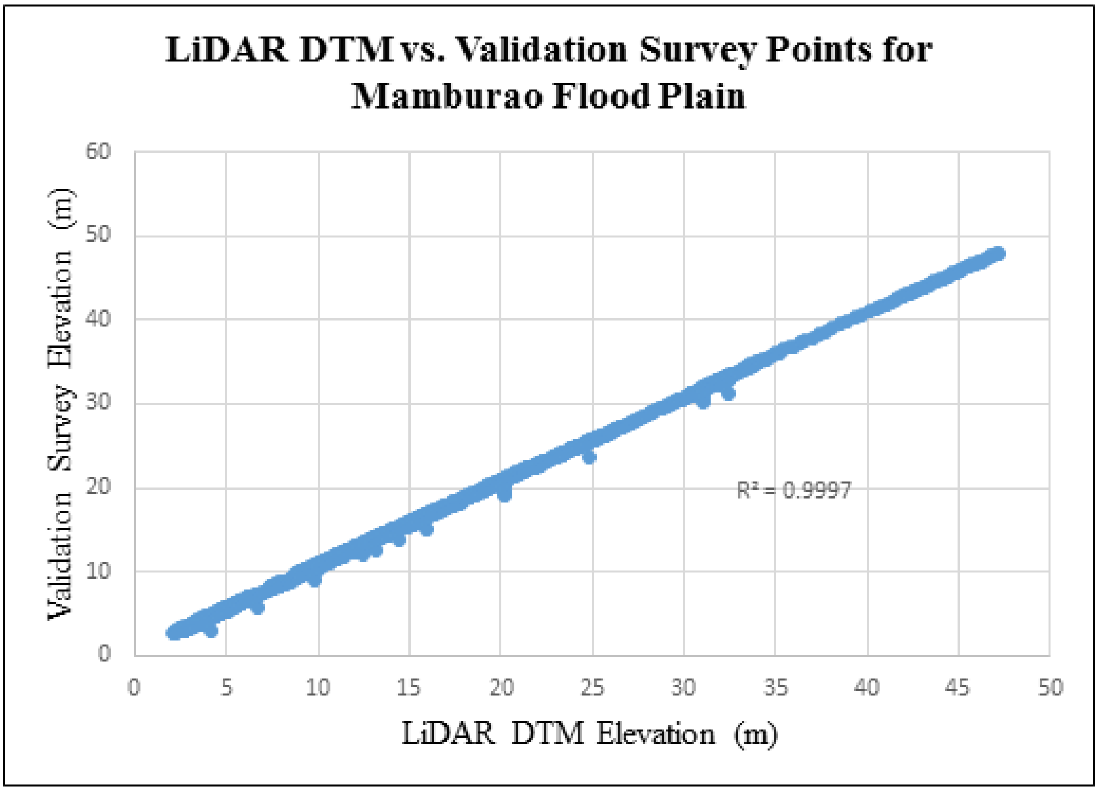

Figure 28. Correlation plot between validation survey points and LiDAR data.

Table 19. Validation Statistical Measures.

Validation Statistical Measures	Value (meters)
RMSE	0.71
Standard Deviation	0.020
Average	-0.68
Minimum	-1.08
Maximum	-0.68

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathymetric data integration, centerline, zigzag, and cross-section were available for Mamburao with a total of 2596 survey points. The resulting raster surface produced was done by Kernel Interpolation with Barrier method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.37 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Mamburao integrated with the processed LiDAR DEM is shown in Figure 29.

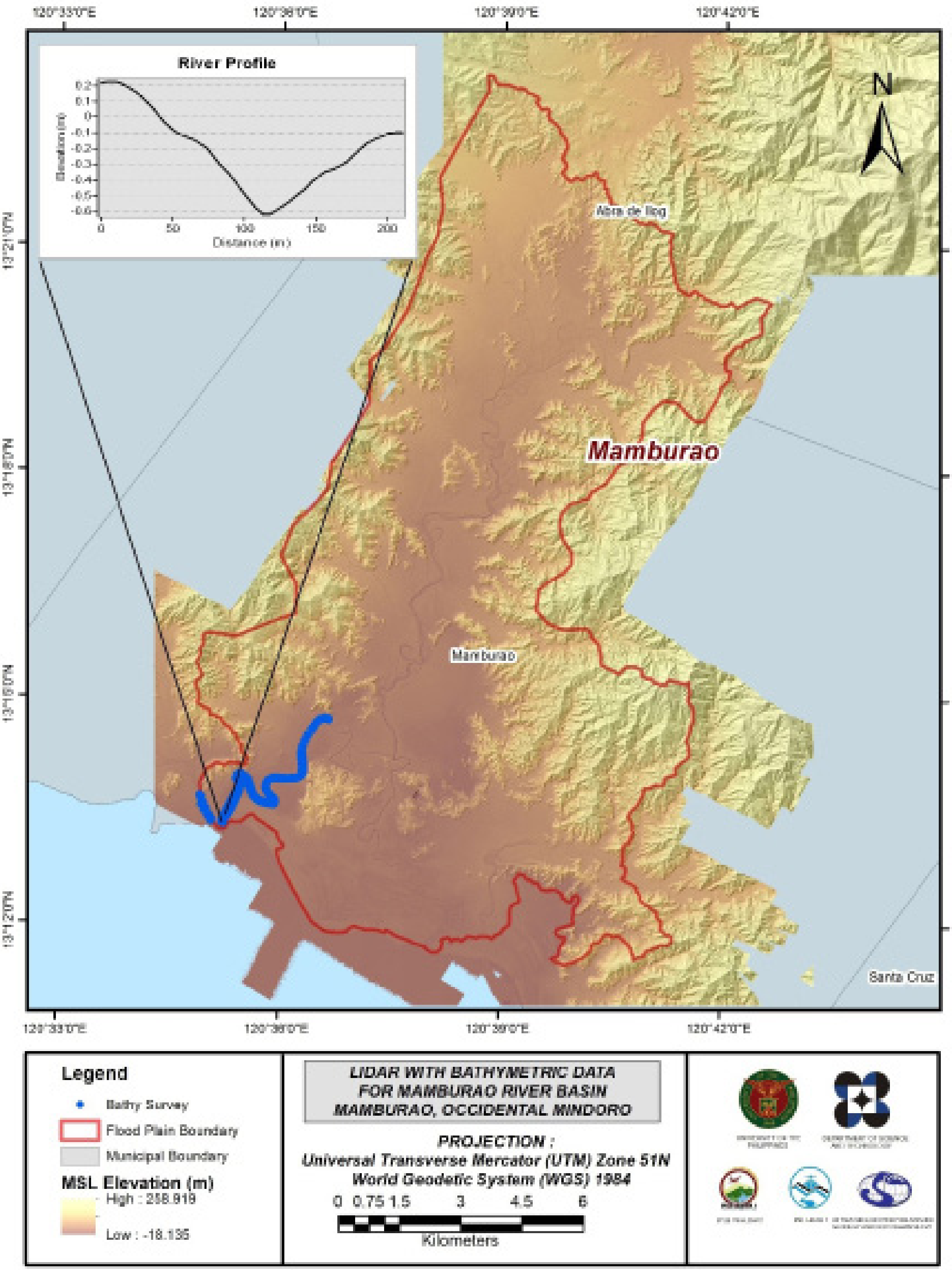

Figure 29. Map of Mamburao Flood Plain with bathymetric survey points shown in blue.

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF THE MAMBURAO RIVER BASIN

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The methods applied in this Chapter were based on the DREAM methods manual (Balicanta, et al., 2014) and further enhanced and updated in Paringit, et al. (2017).

4.1 Summary of Activities

The project team through the help of H.O. Noveloso Surveying (HONS) conducted a field survey in Mamburao River on March 21-23, 2017, on March 25, 2017, and on March 27-29, 2017, with the following scope: reconnaissance; control survey for the establishment of a control point; and cross-section and as-built survey at Mamburao Bridge in Brgy. Poblacion 6, Municipality of Mamburao, Occidental Mindoro; and bathymetric survey of the main river from its upstream in Brgy. San Luis to the mouth of the river located in Brgy. Poblacion 7, in the Municipality of Mamburao, Occidental Mindoro, and its tributary in Brgy. Tayamaan, Municipality of Mamburao, with an approximate length of 6.565 km using a dual frequency HI-Target™ GPS (RTK) and a HI-Target™ Single Beam Echo Sounder and a Sokkia™ Set CX Total Station. The entire survey extent is illustrated in Figure 30.

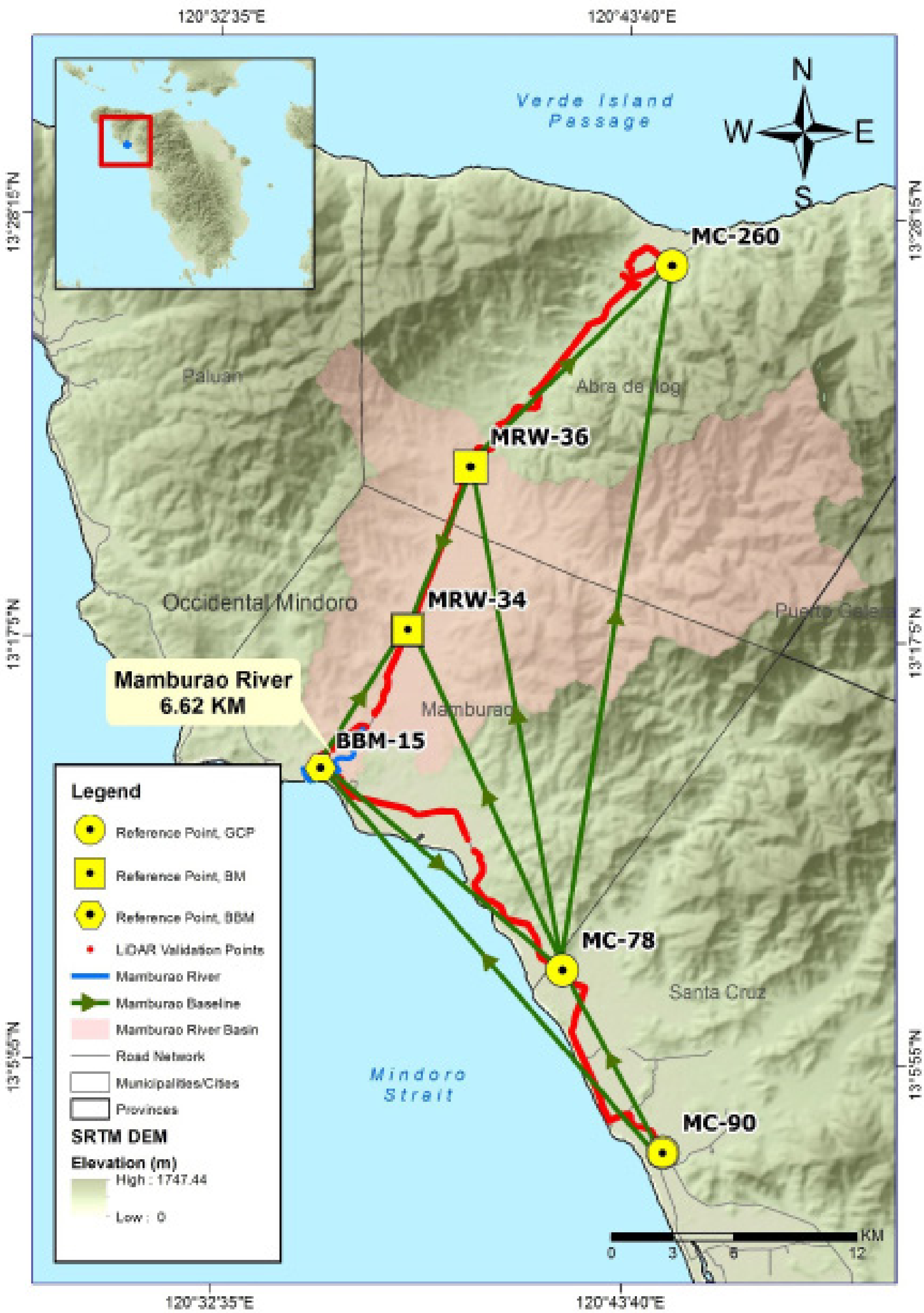


Figure 30. Extent of the bathymetric survey (blue line) in Mamburao River and the LiDAR data validation survey (red)

4.2 Control Survey

The GNSS network used for Mamburao River is composed of four (4) loops established on January 26-29, 2017 occupying the following reference point: MC-90, a first-order BM, in Brgy. Lumangbayan, Sta. Cruz, Occidental Mindoro.

Five (5) NAMRIA established points, MRW-34, in Brgy. Tangkalan, Mamburao, Occidental Mindoro; MRW-36, in Brgy. Armado, Abra de Ilog, Occidental Mindoro; MC-78, in Brgy. San Vicente, Sta. Cruz, Occidental Mindoro; MRW-260, in Brgy. Tibag, Abra de Ilog, Occidental Mindoro; and BBM-15, in Brgy. Poblacion 6, Mamburao, Occidental Mindoro, were used as markers.

Table 20. List of reference and control points used during the survey in Mamburao River (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoidal Height (m)	Elevation in MSL (m)	Date Established
MC-90	1st Order, BM	13°03'34.14427"	120°44'46.70844"	-	8.195	2007
MRW-34	Used as marker	-	-	-		2007
MRW-36	Used as marker	-	-	-	-	2007
MC-78	Used as marker	-	-	-	-	2007
MC-260	Used as marker	-	-	-	-	2008
BBM-15	Used as marker	-	-	-	-	-

The summary of reference and control points and its location is summarized in Table 20 while GNSS network established is illustrated in Figure 31.

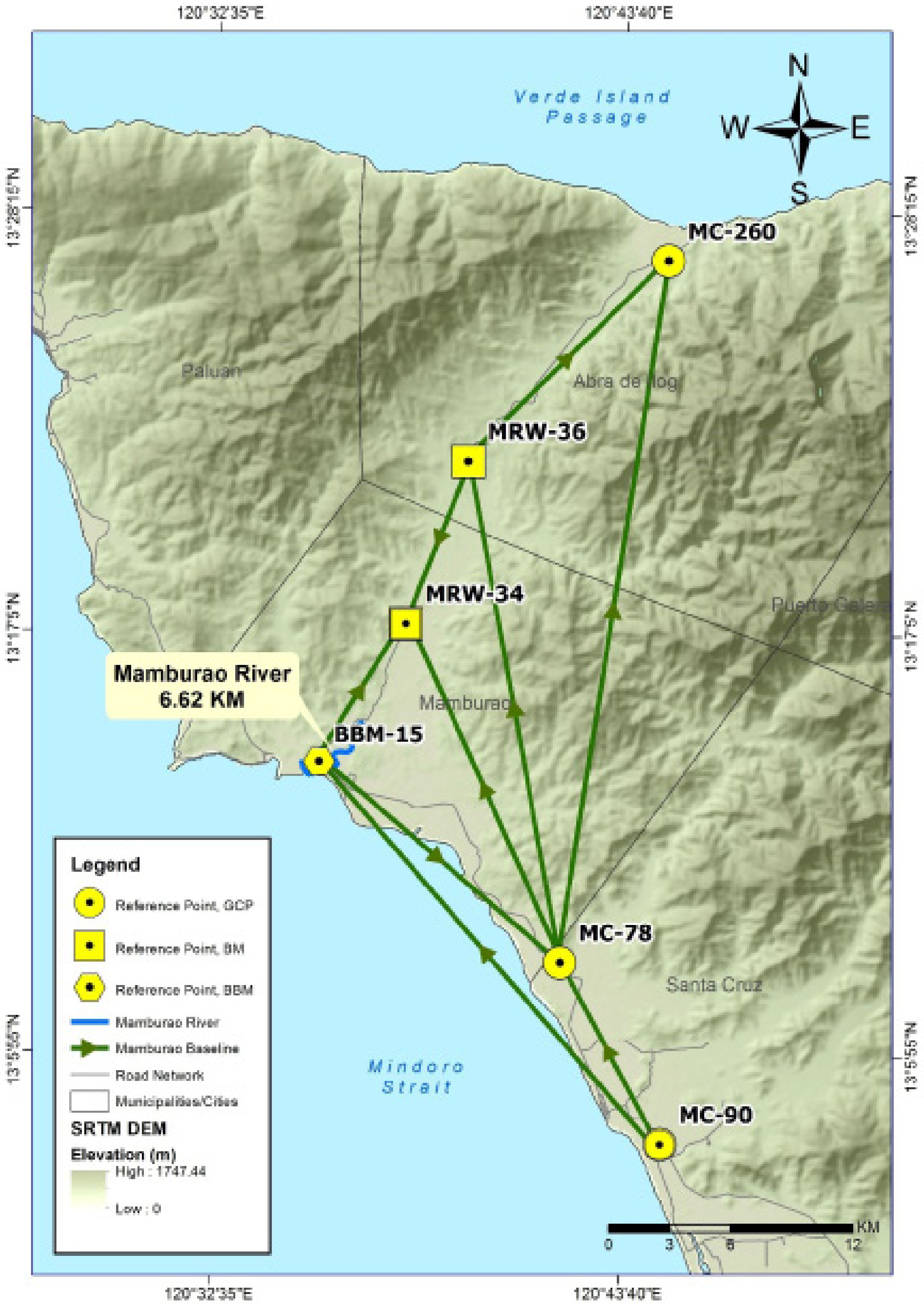


Figure 31. Mamburao River Basin Control Survey Extent

The GNSS set-ups on recovered reference points and established control points in Mamburao River are shown from Figure 32 to Figure 37.

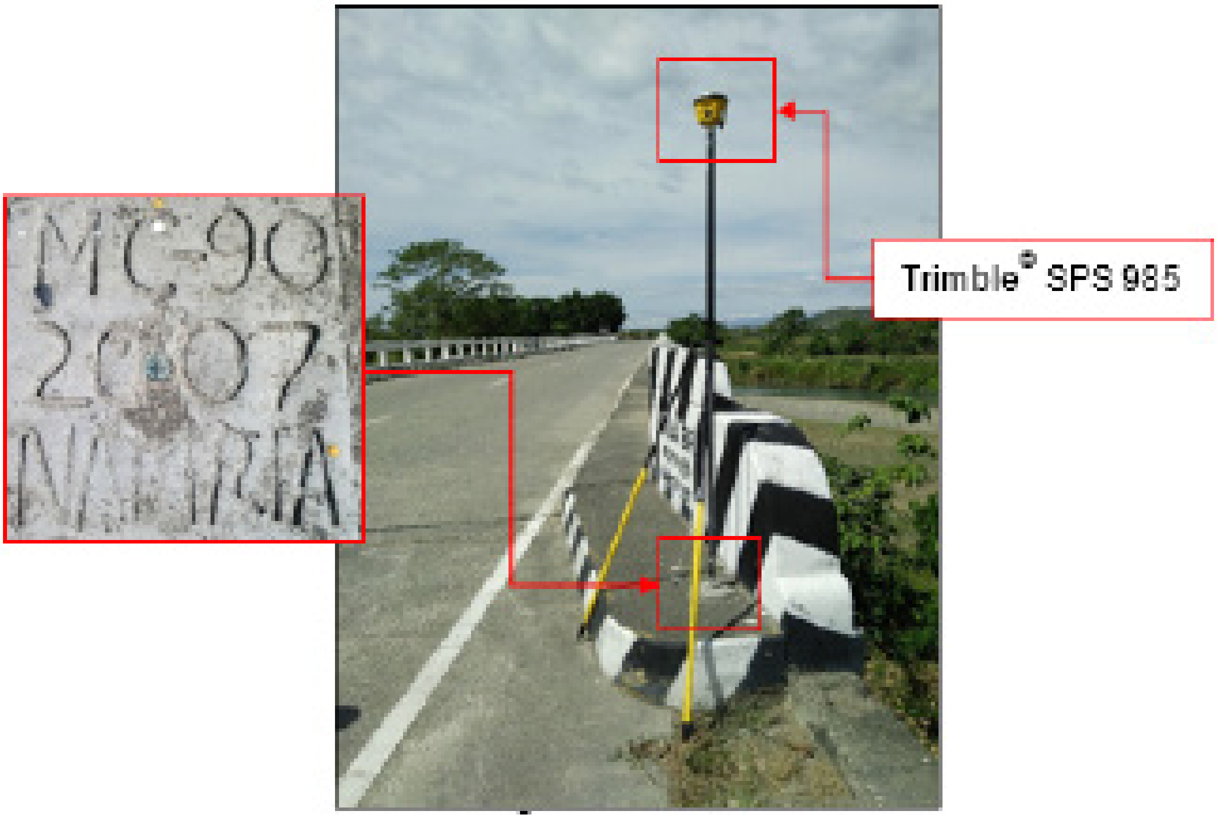


Figure 32. GNSS base set up, Trimble® SPS 985, at MC-90, located at the approach of Pola Bridge in Brgy. Lumangbayan, Sta. Cruz, Occidental Mindoro

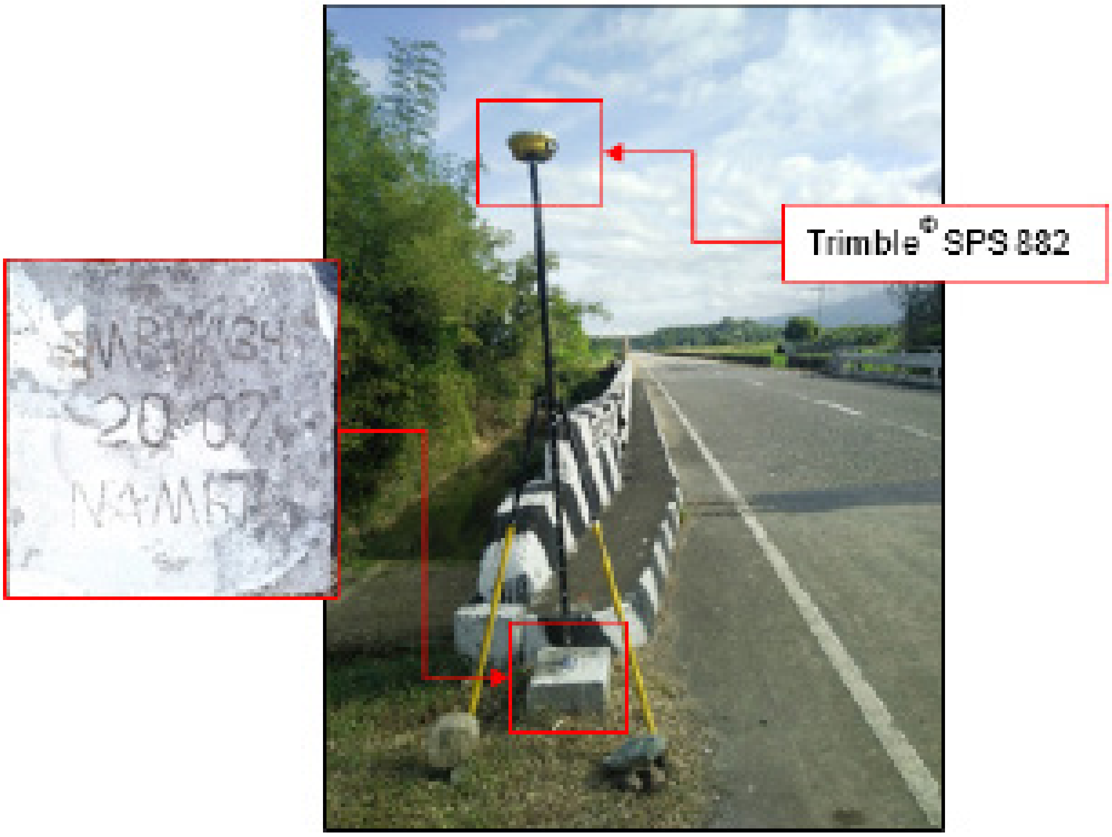


Figure 33. GNSS receiver set up, Trimble® SPS 882, at MRW-34, located beside the approach of Balibago Bridge in Brgy. Tangkalan, Mamburao, Occidental Mindoro

Figure 34. GNSS receiver set up, Trimble® SPS 882, at MRW-36, located beside the approach of Baclaran Bridge in Brgy. Armado, Abra de Ilog, Occidental Mindoro

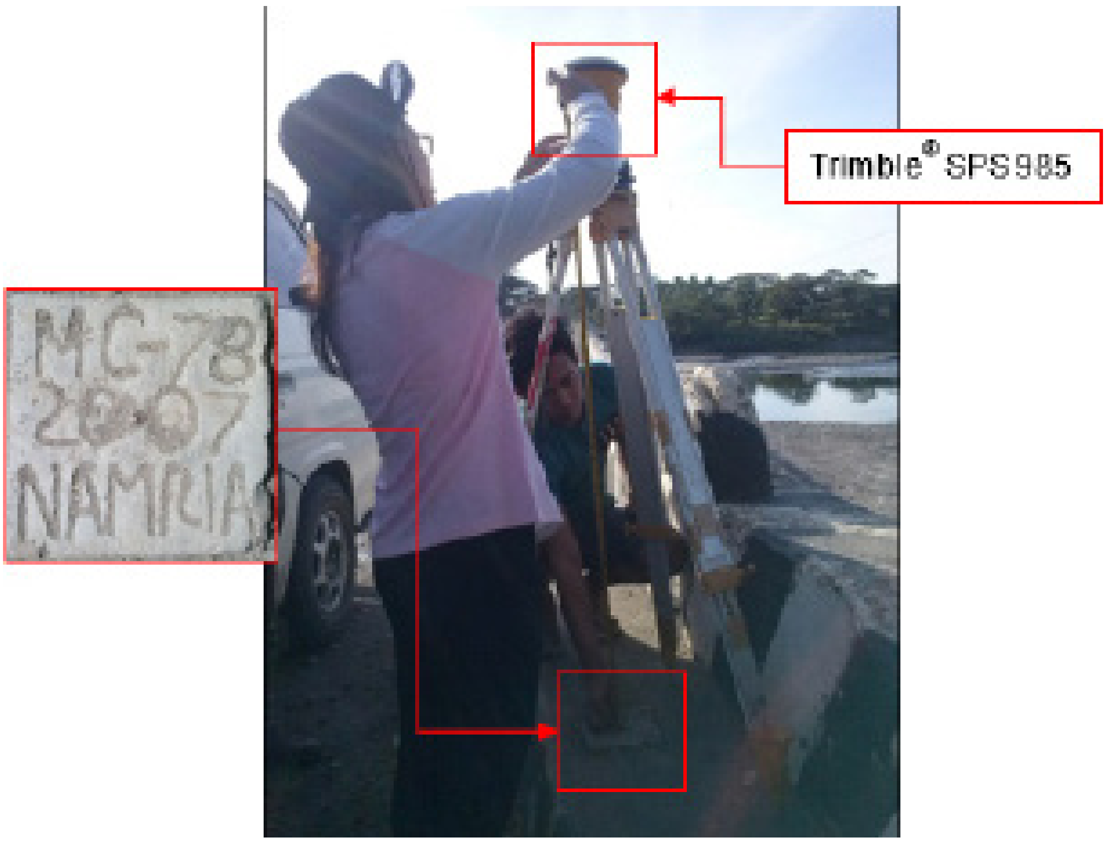


Figure 35. GNSS receiver set up, Trimble® SPS 985, at MC-78, located beside at the approach of Pagbahan Bridge in Brgy. San Vicente, Sta. Cruz, Occidental Mindoro

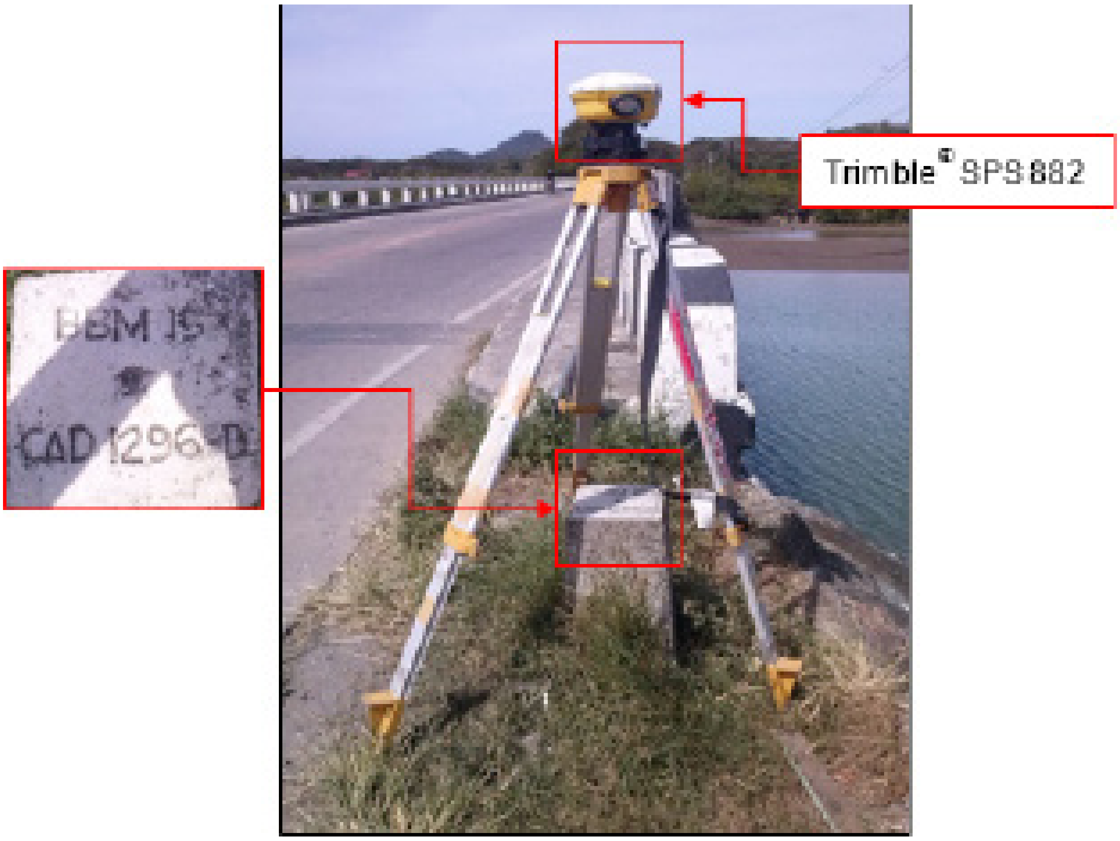


Figure 36. GNSS receiver set up, Trimble® SPS 882, at MC-260, located beside KM Post 442 near Lumangbayan Bridge in Brgy. Tibag, Abra de Ilog, Occidental Mindoro

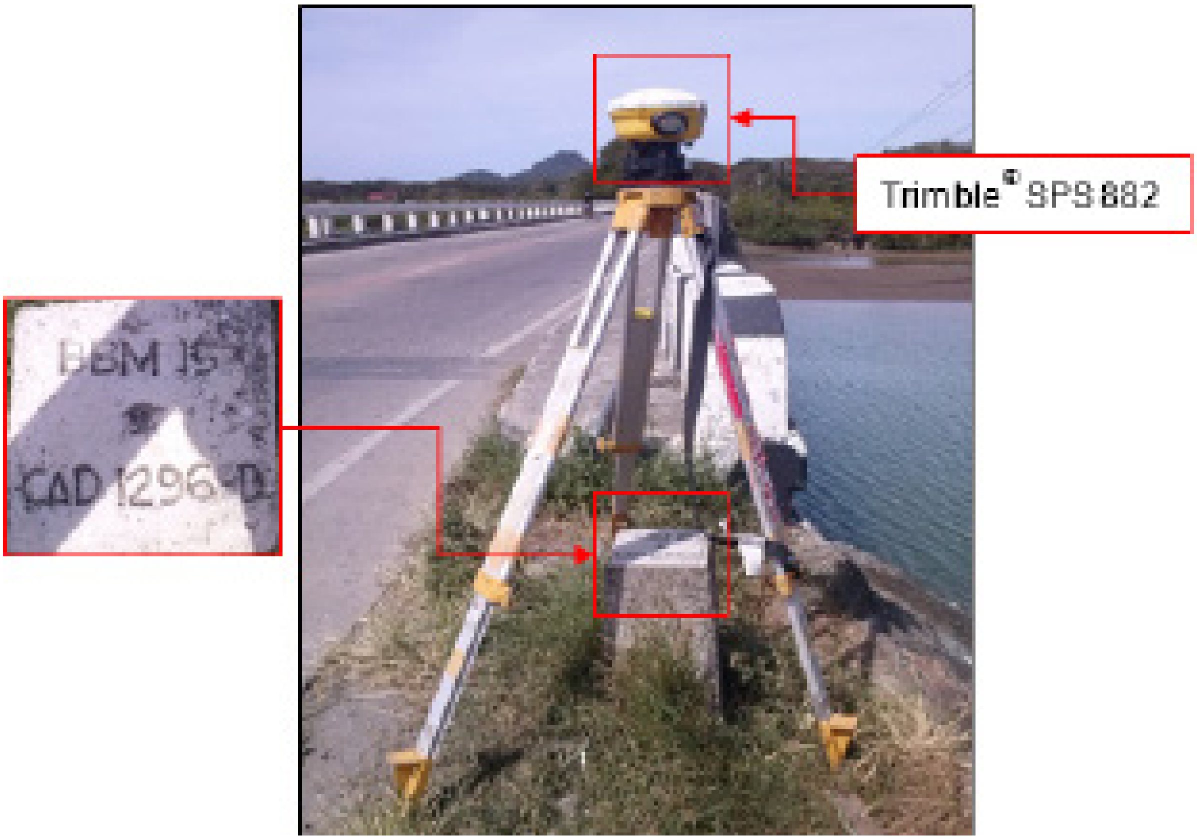


Figure 37. GNSS receiver set up, Trimble® SPS 882, at BBM-15, located beside the approach of Mamburao Bridge in Brgy. Poblacion 6, Mamburao, Occidental Mindoro

4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking is performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Baseline processing result of control points in Mamburao River Basin is summarized in Table 21 generated by TBC software.

Table 21. Baseline Processing Report for Mamburao River Static Survey

Observation	Date of Observation	Solution Type	H. Prec. (m)	V. Prec (m)	Geodetic Az.	Ellipsoid Dist. (m)	ΔHeight (Meter)
BBM-15 --- MC-90	1-28-2017	Fixed	0.003	0.016	317°49'21"	25097.759	-4.522
MC-90--- MC-78	1-28-2017	Fixed	0.004	0.016	330°35'31"	10150.980	-0.061
MC-78--- MRW-36	1-26-2017 1-27-2017	Fixed	0.003	0.016	24938.405	24938.405	23.344
MC-78--- MC-260	1-26-2017	Fixed	0.003	0.017	8°21'06"	34751.555	-0.465
MC-78--- MRW-34	1-27-2017 1-28-2017 1-29-2017	Fixed	0.004	0.016	335°07'38"	18224.640	-0.041
MRW-34 --- BBM-15	1-27-2017 1-28-2017 1-29-2017	Fixed	0.004	0.021	31°46'19"	7977.493	4.428
BBM-15 --- MC-78	1-27-2017 1-28-2017 1-29-2017	Fixed	0.004	0.020	129°23'20"	15362.555	4.449
MRW-36 --- MC-260	1-26-2017	Fixed	0.003	0.017	44°31'56"	13874.000	-23.801
MRW-36 --- MRW-34	1-27-2017	Fixed	0.003	0.016	200°31'17"	8500.251	-23.362

As shown Table 21 a total of nine (9) baselines were processed with coordinate and elevation values of MC-90 held fixed. All of them passed the required accuracy.

4.4 Network Adjustment

After the baseline processing procedure, network adjustment is performed using TBC. Looking at the Adjusted Grid Coordinates table of the TBC generated Network Adjustment Report, it is observed that the square root of the squares of x and y must be less than 20 cm and z less than 10 cm in equation form:

$$\sqrt{((x_e)^2 + (y_e)^2)} < 20 \text{ cm and } z_e < 10\ cm$$

Where:

x_e is the Easting Error,
y_e is the Northing Error, and
z_e is the Elevation Error

for each control point. See the Network Adjustment Report shown from Table 22 to 25 for the complete details. Refer to Annex 11 for the computation for the accuracy of HONS.
The six (6) control points, MC-90, MRW-34, MRW-36, MC-78, MC-260, and BBM-15, were occupied and observed simultaneously to form a GNSS loop. The coordinate and elevation values of MC-90 were held fixed during the processing of the control points as presented in Table 22. Through this reference point, the coordinates and elevations of the unknown control points will be computed.

Table 22. Control Point Constraints

Point ID	Type	**East σ (Meter)**	**North σ (Meter)**	**Height σ (Meter)**	**Elevation σ (Meter)**
MC-90	Grid				Fixed
MC-90	Local	Fixed	Fixed		
Fixed = 0.000001(Meter)					

Table 23. Adjusted Grid Coordinates

Point ID	**Easting (Meter)**	**Easting Error (Meter)**	**Northing (Meter)**	**Northing Error (Meter)**	**Elevation (Meter)**	**Elevation Error (Meter)**	**Constraint**
BBM-15	238917.143	0.009	1463556.933	0.007	6.091	0.055	
MC-78	250700.867	0.010	1453690.640	0.007	8.806	0.056	
MC-90	255607.924	?	1444800.407	?	8.195	?	LLe
MC-260	256067.623	0.013	1488037.689	0.010	8.241	0.079	
MRW-34	243184.693	0.012	1470301.042	0.009	9.791	0.068	
MRW-36	246240.673	0.012	1478236.660	0.009	32.721	0.072	

With the mentioned equation, $\sqrt{((x_e)^2 + (y_e)^2)} < 20$ cm for horizontal and $z_e < 10$ cm for the vertical; the computation for the accuracy are as follows:

a. BBM-15

Horizontal accuracy = $\sqrt{((0.9)^2 + (0.7)^2}$
= $\sqrt{(0.81 + 0.49)}$
= 1.14 < 20 cm

Vertical accuracy = 5.5 < 10 cm

b. MC-78

Horizontal accuracy = $\sqrt{((1.0)^2 + (0.7)^2}$
= $\sqrt{(1.00 + 0.49)}$
= 1.22 < 20 cm

Vertical accuracy = 5.6 < 10 cm

c. MC-90

Horizontal accuracy = Fixed

Vertical accuracy = Fixed

d. MC-260

Horizontal accuracy = $\sqrt{((1.3)^2 + (1.0)^2}$
= $\sqrt{(1.69 + 1.00)}$
= 1.64 < 20 cm

Vertical accuracy = 7.9 < 10 cm

e. MRW-34

Horizontal accuracy = $\sqrt{((1.2)^2 + (0.9)^2}$
= $\sqrt{(1.44 + 0.81)}$
= 1.50 < 20 cm

Vertical accuracy = 6.8 < 10 cm

f. MRW-36

Horizontal accuracy = $\sqrt{((1.2)^2 + (0.9)^2}$
= $\sqrt{(1.44 + 0.81)}$
= 1.50 < 20 cm

Vertical accuracy = 7.2 < 10 cm

Following the given formula, the horizontal and vertical accuracy result of the occupied control point is within the required precision.

Table 24. Adjusted Geodetic Coordinates

Point ID	Latitude	**Longitude**	**Height (Meter)**	**Height Error (Meter)**	**Constraint**
BBM-15	N13°13'39.19826"	E120°35'26.99118"	48.714	0.055	
MC-78	N13°08'21.88467"	E120°42'01.21159"	53.170	0.056	
MC-90	N13°03'34.14427"	E120°44'46.70844"	53.232	?	LLe
MC-260	N13°27'00.69333"	E120°44'49.01983"	52.702	0.079	
MRW-34	N13°17'19.87652"	E120°37'46.54458"	53.137	0.068	
MRW-36	N13°21'38.92732"	E120°39'25.54335"	76.503	0.072	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 24. Based on the result of the computation, the accuracy conditions are satisfied; hence, the required accuracy for the program was met.

The summary of reference control points used is indicated in Table 25.

Table 25. Reference and control points used and its location (Source: NAMRIA, UP-TCAGP)

Point ID	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
MC-90	1st Order, BM	13°03'34.14427"	120°44'46.70844"	53.232	1444800.407	255607.924	8.195
MRW-34	Used as marker	13°17'19.87652"	120°37'46.54458"	53.137	1470301.042	243184.693	9.791
MRW-36	Used as marker	13°21'38.92732"	120°39'25.54335"	76.503	1478236.660	246240.673	32.721
MC-78	Used as marker	13°08'21.88467"	120°42'01.21159"	53.170	1453690.640	250700.867	8.806
MC-260	Used as marker	13°27'00.69333"	120°44'49.01983"	52.702	1488037.689	256067.623	8.241
BBM-15	Used as marker	13°13'39.19826"	120°35'26.99118"	48.714	1463556.933	238917.143	6.091

4.5 Cross-section and Bridge-as-built survey and Water Level Marking

Cross-section and as-built surveys were conducted on March 25, 2017 at the downstream side of Mamburao Bridge in Brgy. Poblacion 6, Mamburao, Occidental Mindoro as shown in Figure 38. A Hi-Target™ GPS in RTK survey technique and a Sokkia™ Set CX Total Station were utilized for this survey as shown in Figure 39.

Figure 38. Downstream side of Mamburao Bridge

Figure 39. Cross-section survey of Mamburao Bridge

The cross-sectional line of Mamburao Bridge is about 1121 m with five hundred sixty-one (561) cross-sectional points using the control points UP-MAM-3 and BBM-15 as the GNSS base stations. The location map, cross-section diagram, and the bridge data form are shown in Figure 40 to Figure 42.

Gathering of random points for the checking of HONS's bridge cross-section and bridge points data was performed by DVBC on January 31, 2017 using a survey grade GNSS Rover receiver attached to a 2-m pole.

Root Mean Square (RMSE) analysis is performed in order to assess the difference in elevation between the DVBC checking points and the contractor's. The RMSE value should only have a maximum radial distance of 5 m and the difference in elevation within the radius of 5 meters should not be beyond 0.50 m. For the bridge cross-section data, a computed value of 0.171 was acquired. The computed R2 and RMSE values are within the accuracy requirement of the program.

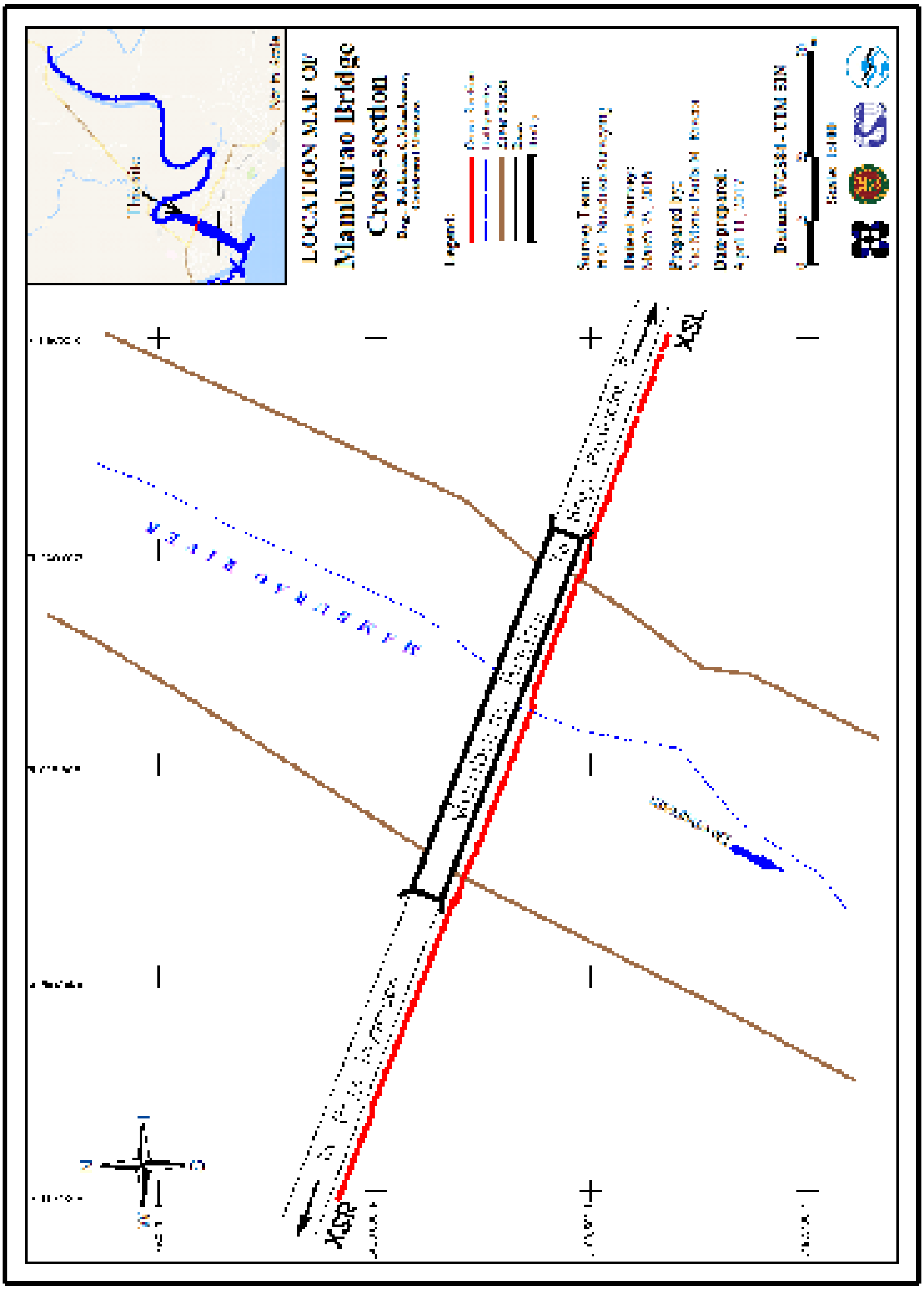


Figure 40. Location Map of Mamburao Bridge Cross-Section

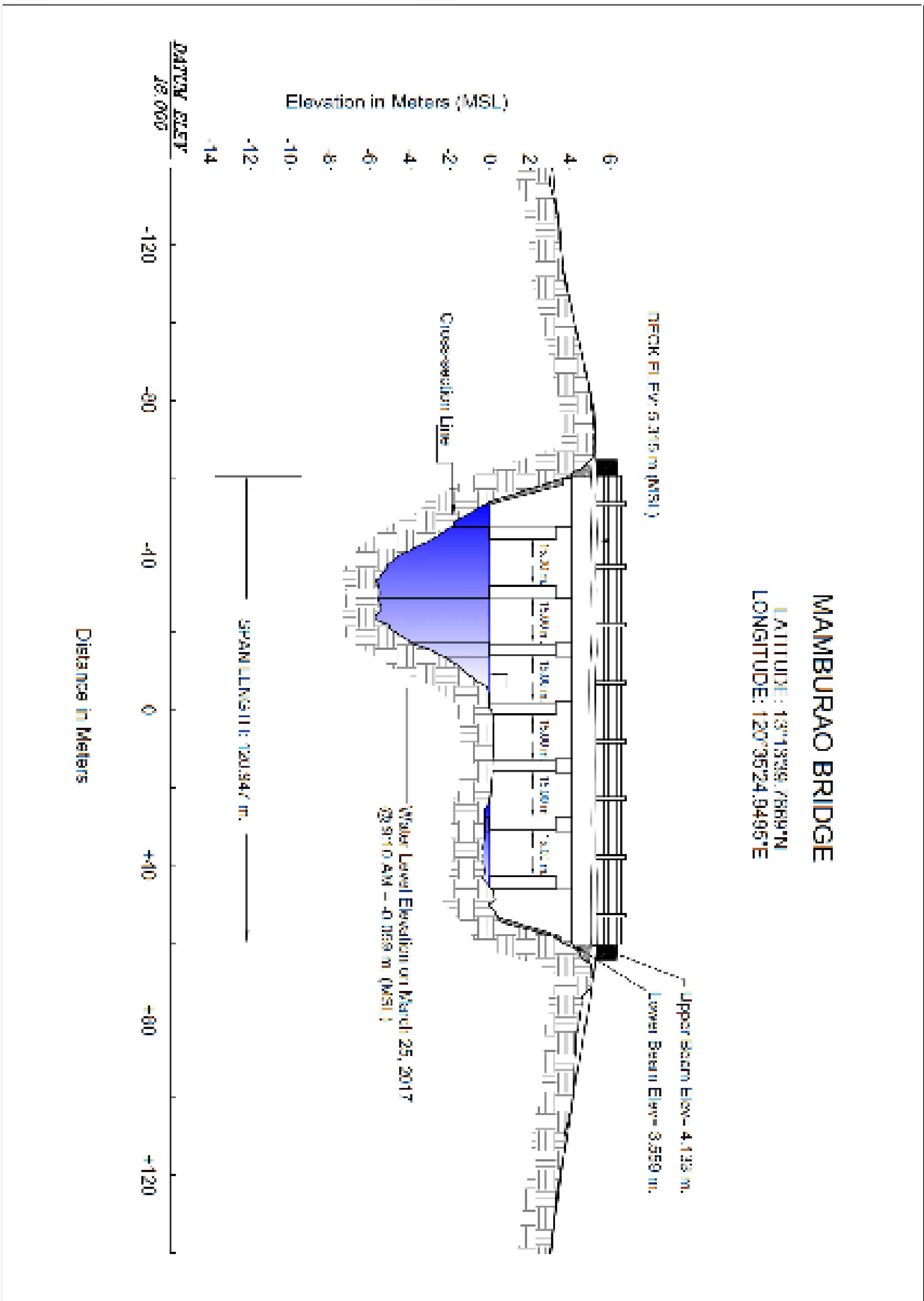


Figure 41. Pagbahan Bridge Cross-section Diagram

BRIDGE DATA FORM

Bridge Name: Mamburao Bridge

River Name: Mamburao River

Location (Brgy., City, Region): Brgy. Poblacion 6, Mamburao, Occidental Mindoro

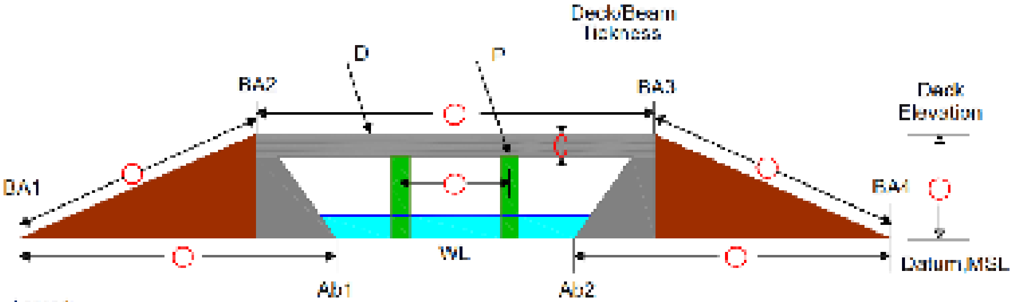
Survey Team: Julielo Cabilin, Romualdo Abelido, Eduardo Cuizon, Ronald Dalun
Jerry Domingo, Bogart Bolano

Date and Time: March 25, 2017 @ 8:00 am - 5:00 pm

Flow Condition: Low Normal High

Weather Condition: Fair Rainy

Cross-sectional View (not to scale)



Legend:
BA = Bridge Approach
P = Pier
Ab = Abutment
D = Deck
WL = Water Level/Surface
MSL = Mean Sea Level
◯ = Measurement Value

Line Segment	Measurement, m	Remarks
1. BA1-BA2	4.076 m.	Concrete
2. BA2-BA3	120.347 m.	Concrete
3. BA3-BA4	4.187 m.	Concrete
4. BA1-Ab1	11.719 m.	Concrete
5. Ab2-BA4	10.963 m.	Concrete
6. Deck/Beam thickness	0.574 m.	Concrete
7. Deck Elevation	5.315 m. MSL	Concrete
8. P1-P2	15.000 m.	Concrete
9. P2-P3	15.000 m.	Concrete
10. P3-P4	15.000 m.	Concrete
11. P4-P5	15.000 m.	Concrete
12. P5-P6	15.000 m.	Concrete
13. P6-P7	15.000 m.	Concrete

Note: Observer should be facing downstream

Figure 42. Mamburao Bridge Data Sheet

Water surface elevation of Mamburao River was determined by a Sokkia™ Set CX Total Station on March 25, 2017 at the railings Mamburao Bridge in Brgy. Poblacion 6, Mamburao, Occidental Mindoro with a value of 5.522 m in MSL. This was translated into marking on the bridge's sidewalk 2.5 meters away from the centerline as shown in Figure 43.

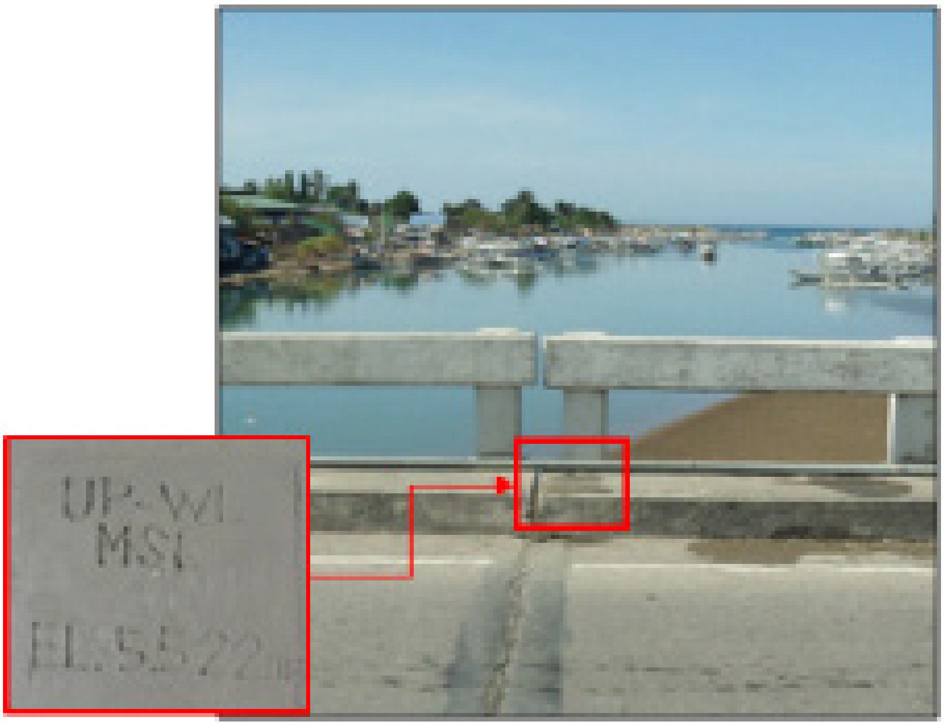


Figure 43. Water surface elevation marking on Mamburao Bridge sidewalk

Water surface elevation of Mamburao River was also determined by a Sokkia™ Set CX Total Station on March 25, 2017 at 9:10 AM at Mamburao Bridge area with a value of -0.059 m in MSL as shown in Figure 44. This was translated into marking on the bridge's pier as shown in Figure 45. The markings will serve as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Mamburao River, the University of the Philippines Los Baños.

Figure 44. Water level markings on the pier of Mamburao Bridge

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted by DVBC on January 26-29, 2017 using a survey grade GNSS Rover receiver, Trimble ® SPS 882, mounted on a range pole which was attached on the side of the vehicle as shown in Figure 45. It was secured with cable ties and ropes to ensure that it was horizontally and vertically balanced. The antenna height was 2.05 m and measured from the ground up to the bottom of the antenna mount of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with MC-78 and MC-90 occupied as the GNSS base stations in the conduct of the survey.

Figure 45. Validation points acquisition survey set-up for Mamburao River

The survey started from Brgy. Tibag, Abra de Ilog, Occidental Mindoro going southeast along the national highway, covering five (5) barangays in Abra de Ilog, fourteen (14) barangays in Mamburao, five (5) barangays in Santa Cruz, and ended in Brgy. Barahan, Santa Cruz, Occidental Mindoro. The survey gathered a total of 10,368 points with approximate length of 67.65 km using MC-78 and MC-90 as GNSS base stations for the entire extent of validation points acquisition survey as illustrated in the map in Figure 46.

Figure 46. LiDAR validation points acquisition survey extent in Tago River Basin

4.7 Bathymetric Survey

Bathymetric survey was executed on March 25, 2017 using a dual frequency Hi-Target™ V30 GNSS and a Hi-Target™ Single Beam Echo Sounder mounted in a motor boat as illustrated in Figure 47. The survey started in Brgy. Payompon, Mamburao, Occidental Mindoro, with coordinates 13°14'42.01"N, 120°36'40.70"E and ended at the mouth of the river in Brgy. Poblacion 7, also in the Municipality of Mamburao, with coordinates 13°13'31.1245"N, 120°35'20.6534"E.The control points UP-MAM-3, UP-MAM-4, and UP-MAM-5 were used as the GNSS base stations throughout the survey.

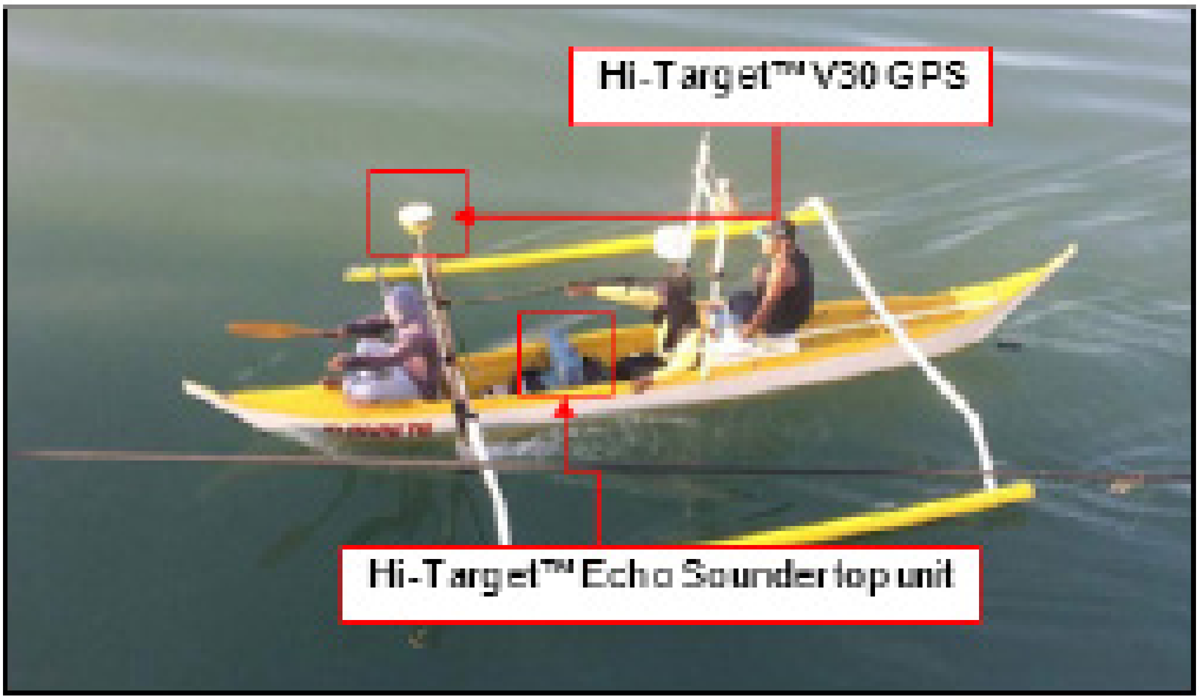


Figure 47. Bathymetric survey of HONS along Mamburao River

Manual bathymetric survey, on the other hand, was executed from March 27-29, 2017 using a Hi-Target™ V30 GNSS and a Sokkia™ Set CX Total Station as illustrated in Figure 48. The survey in the main river started in Brgy. San Luis, Mamburao, Occidental Mindoro with coordinates 13°14'41.7399"N, 120°36'41.1245"E, traversing the river and ended at the starting point of the bathymetric survey using a boat in Brgy. Payompon, Mamburao, Occidental Mindoro. The survey continued from Brgy. Poblacion 7, Mamburao, Occidental Mindoro with coordinates 13°13'31.1245"N, 120°35'20.6534"E, traversing the river and ended at the mouth of the river in Brgy. Poblacion 7 as well with coordinates 13°13'19.8413"N, 120°35'14.4686"E. For the tributary, the survey coverage is within Brgy. Tayamaan, Mamburao, Occidental Mindoro which started with coordinates 13°13'41.2494"N, 120°34'56.3755"E and ended with coordinates 13°13'20.9697"N, 120°35'05.6329"E. The control points UP-MAM-3, UP-MAM-4, and UP-MAM-5 were used as GNSS base stations all throughout the entire survey.

Figure 48. Manual bathymetric survey of HONS along Mamburao River

Gathering of random points for the checking of HONS's bathymetric data was performed by DVBC on January 30, 2017 using a survey grade GNSS Rover receiver attached to a boat as seen in Figure 49. A map showing the DVBC bathymetric checking points is shown in Figure 51.

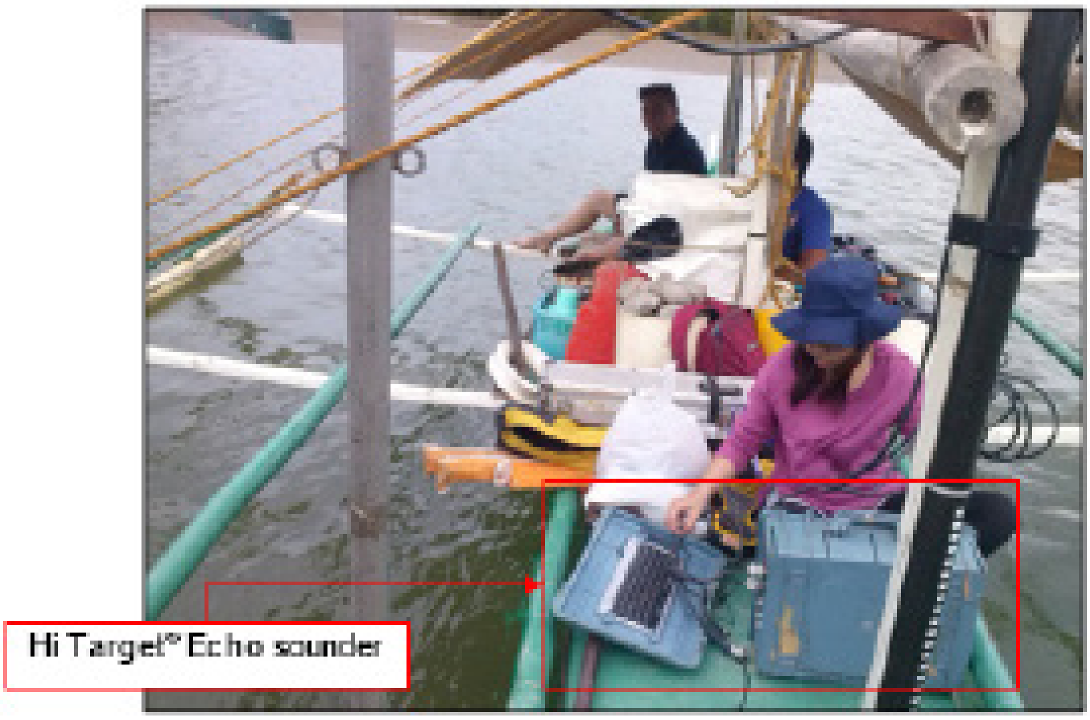


Figure 49. Gathering of random bathymetric points along Mamburao River

RMSE analysis was also performed on the two (2) datasets and an RMSE value of 0.123 for the bathymetric data was obtained. The RMSE value is within the accuracy required by the program.

The bathymetric survey for Mamburao River gathered a total of 3,044 points covering 6.565 km of the river traversing barangays San Luis, Payompon, Poblacion 8, Poblacion 5, Poblacion 6, Poblacion 7, and Tayamaan in the Municipality of Mamburao, Occidental Mindoro. A CAD drawing was also produced to illustrate the riverbed profile of Mamburao River and its tributary. As shown in Figures 52 to 53, the highest and lowest elevation has a 5.106 m difference. The highest elevation observed was 0.048 m above MSL located in Brgy. Tayamaan, in the Municipality of Mamburao, Occidental Mindoro; while the lowest was -5.058 m below MSL located in Brgy. Poblacion 6, also in the Municipality of Mamburao.

Figure 50. Bathymetric survey of Mamburao River

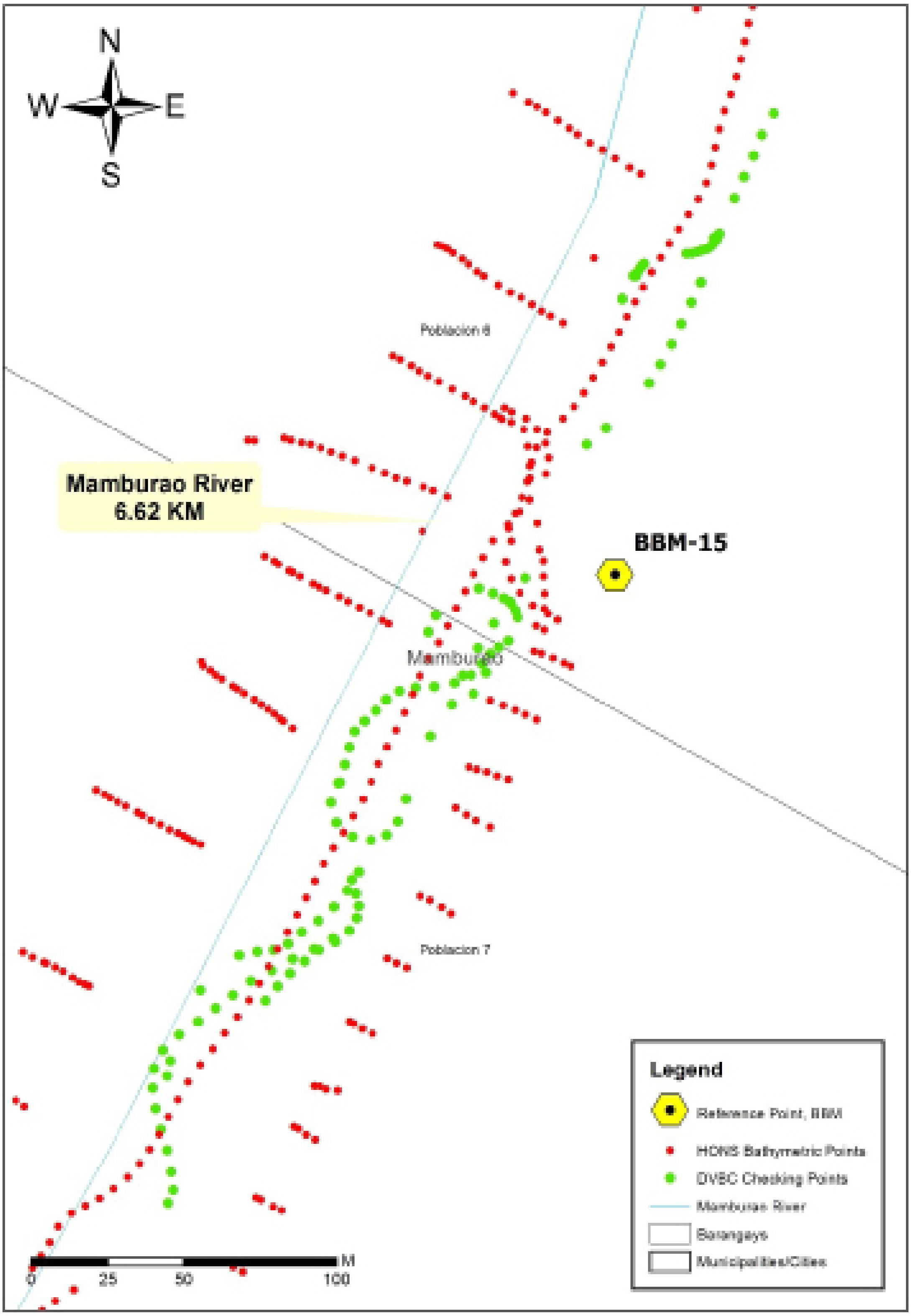


Figure 51. Quality checking points gathered along Mamburao River by DVBC

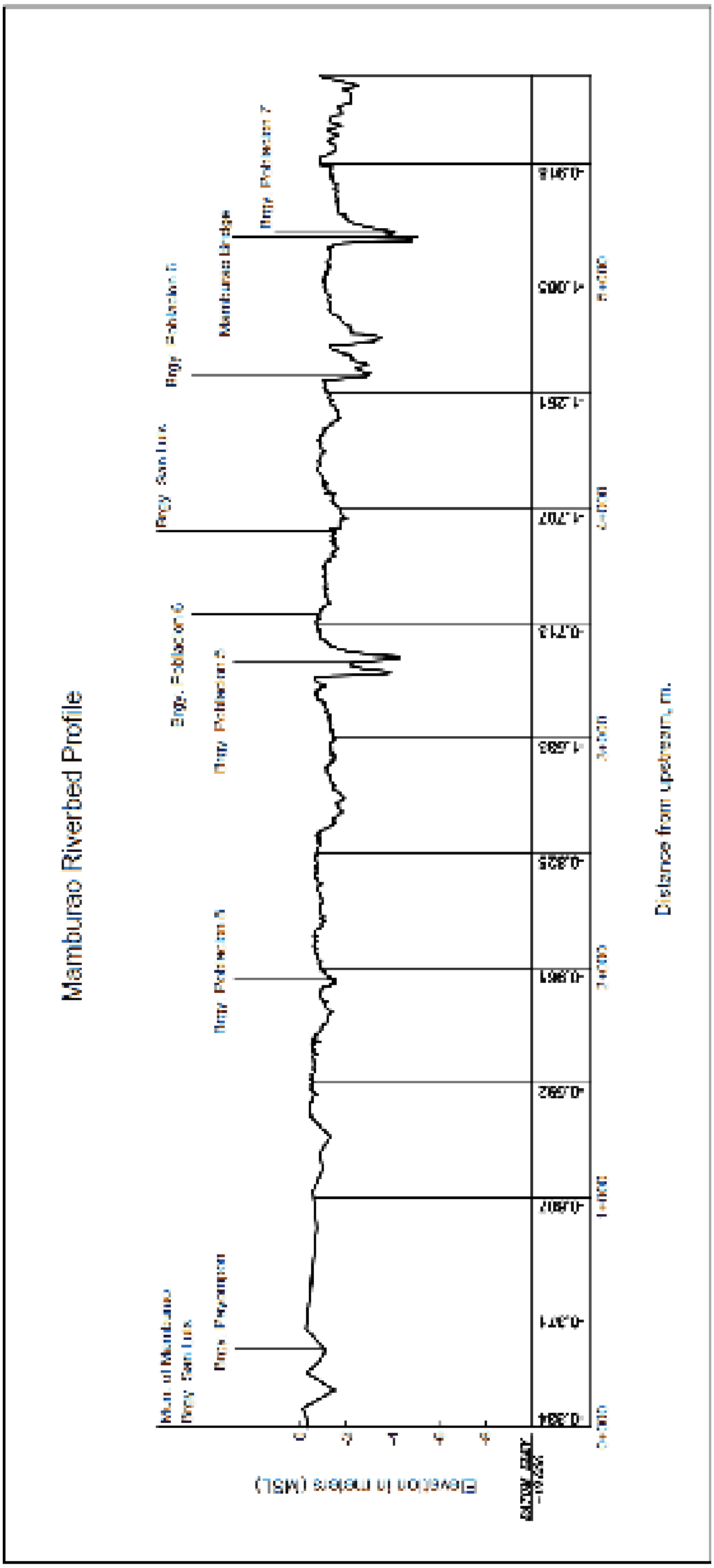


Figure 52. Mamburao Riverbed Profile

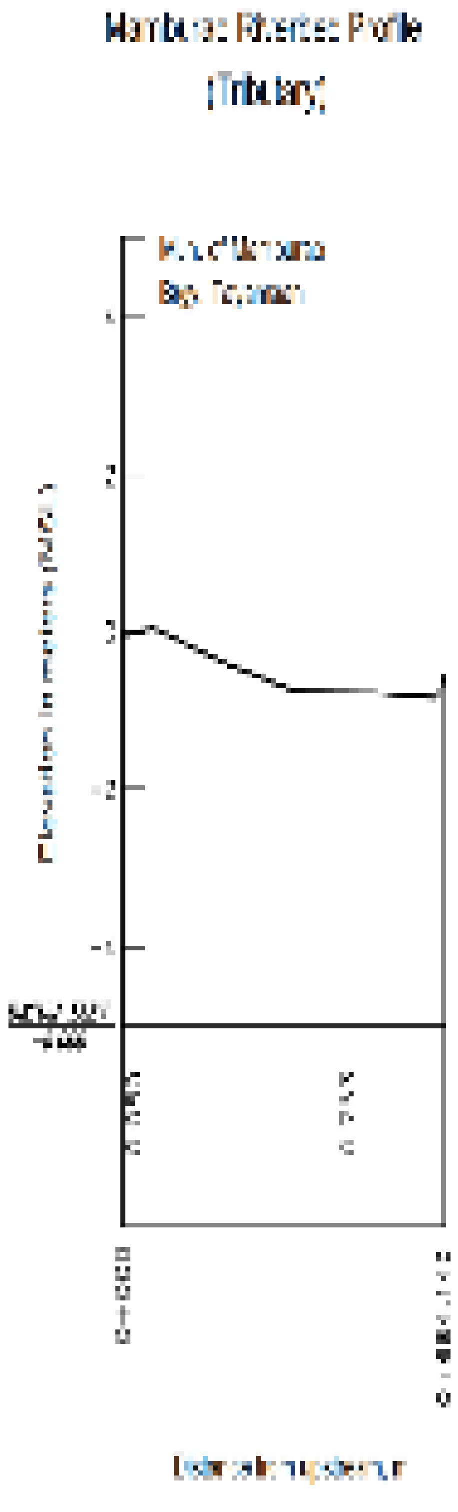


Figure 53. Mamburao Tributary Riverbed Profile

CHAPTER 5: FLOOD MODELING AND MAPPING

Engr. Ma. Rosario Concepcion O. Ang, Engr. John Louie D. Fabila, Engr. Sarah Jane D. Samalburo , Engr. Harmond F. Santos , Engr. Angelo Carlo B. Bongat , Engr. Ma. Ailyn L. Olanda, Engr. Jovelle Anjeanette S. Canlas, Marie Denise V. Bueno , Engr. Regis R. Guhiting, Engr. Merven Matthew D. Natino

The methods applied in this Chapter were based on the DREAM methods manual (Lagmay, et al., 2014) and further enhanced and updated in Paringit, et al. (2017)

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

All data that affect the hydrologic cycle of the river basin was monitored, collected, and analyzed. Rainfall, water level, and flow in a certain period of time, which may affect the hydrologic cycle of the Mamburao River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from a portable rain gauge deployed on a strategic location within the riverbasin (13.2213093°N, 120.6059937°E). The location of the rain gauge is seen in Figure 54.

The total precipitation for this event is 77.724 mm. It has a peak rainfall of 17.780 mm. on August 6, 2016 at 5:15 pm. The lag time between the peak rainfall and discharge is 4 hour and 30 minutes, as seen in Figure 57.

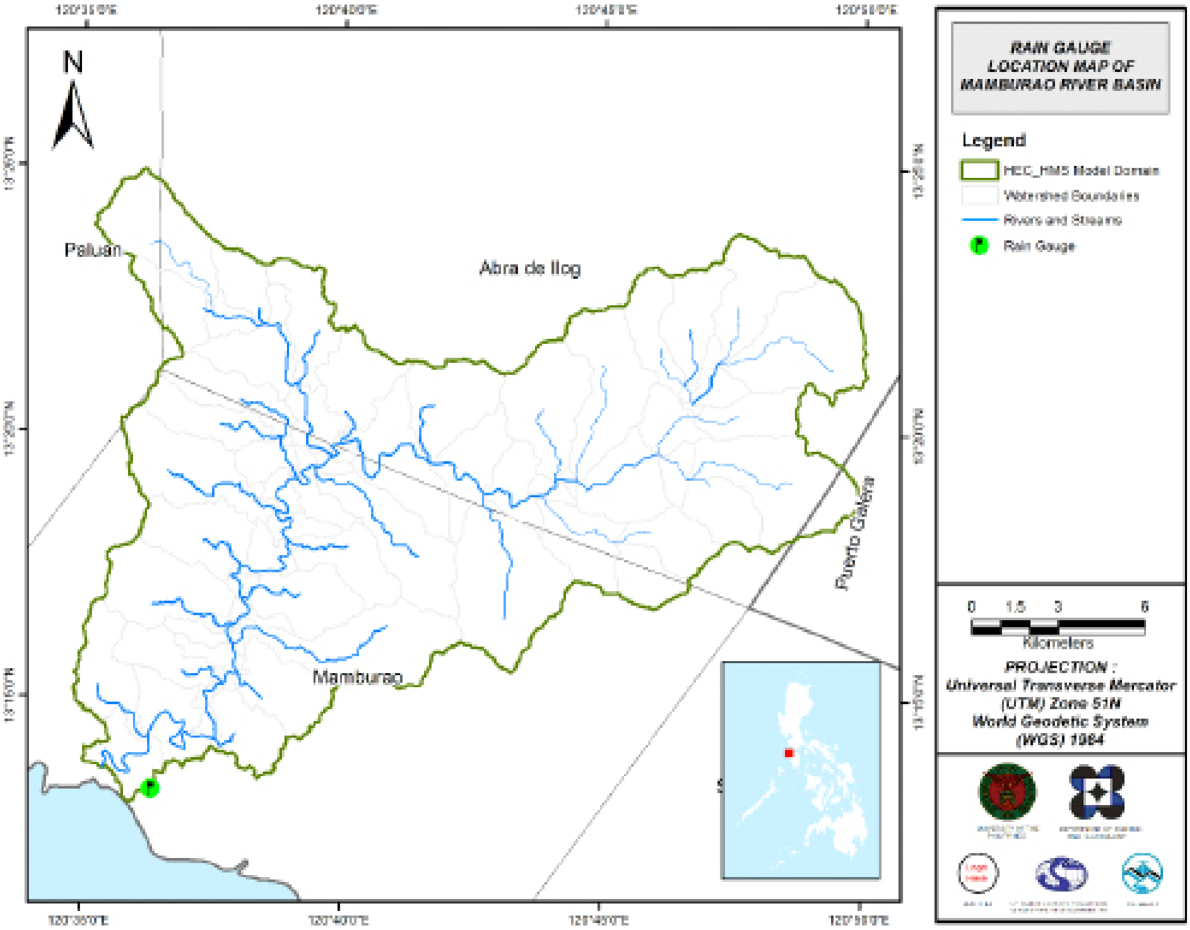


Figure 54. The location map of Mamburao HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Mamburao Bridge, Occidental Mindoro (13.227713° N, 120.590292°E). It gives the relationship between the observed water levels from the Ibod Bridge and outflow of the watershed at this location using Bankfull Method in Manning's Equation.

For Mamburao Bridge, the rating curve is expressed as Q = 2E-15e0.8297x as shown in Figure 56.

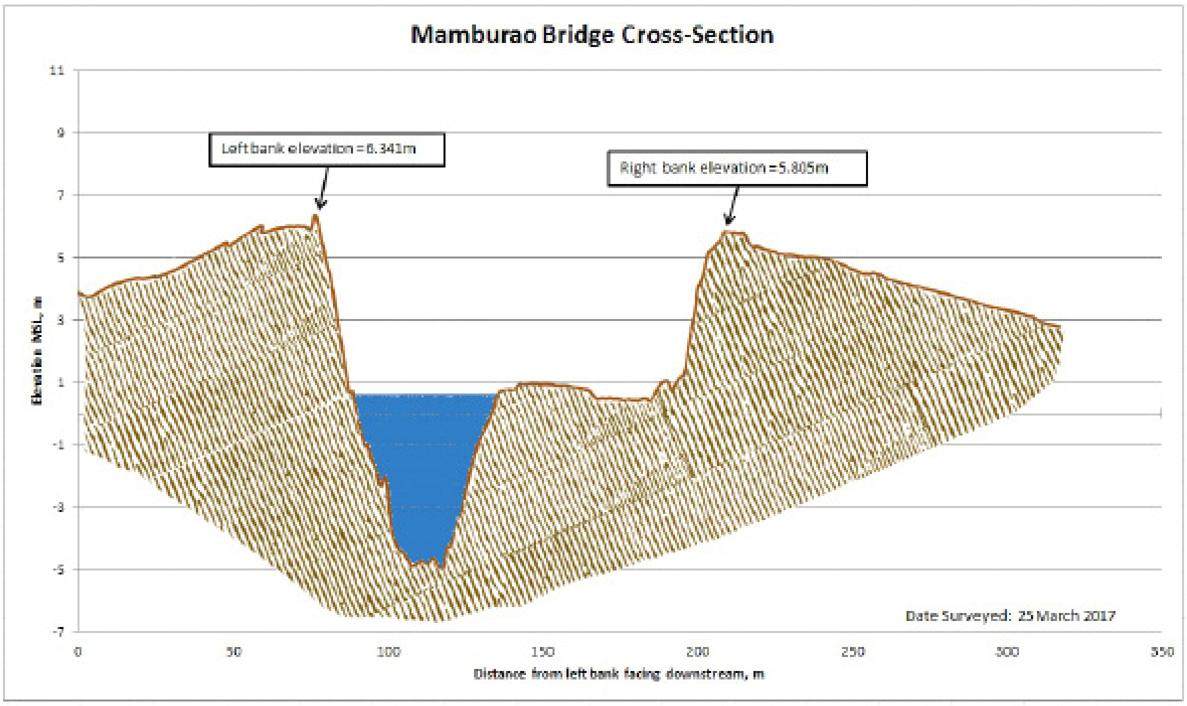


Figure 55. Cross-Section Plot of Mamburao Bridge

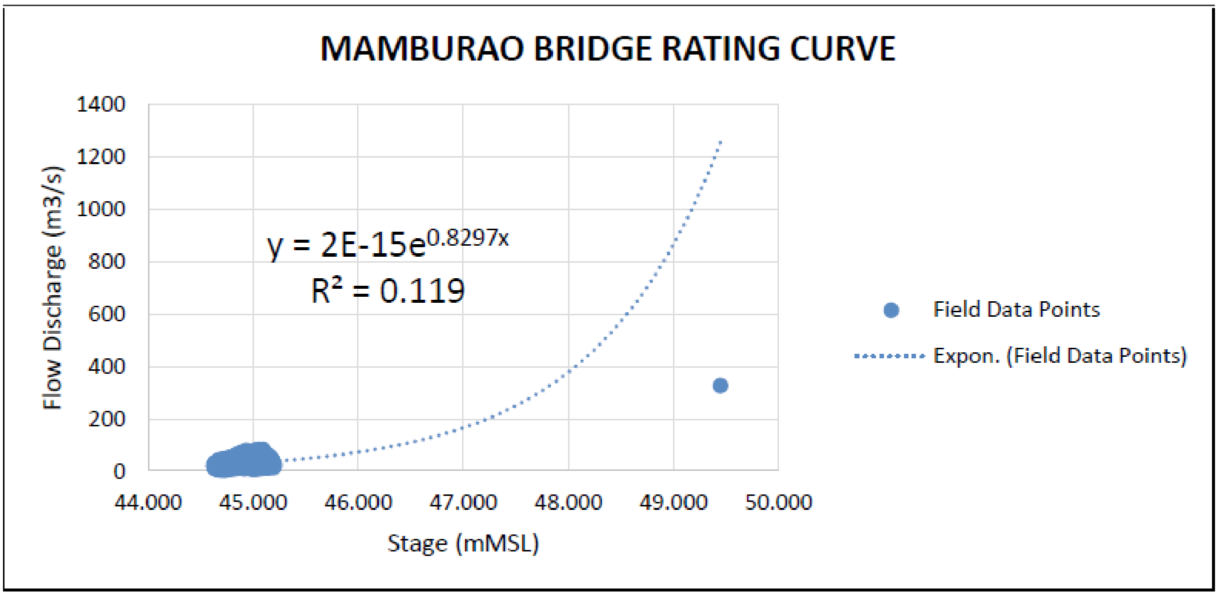


Figure 56. Rating Curve at Mamburao, Occidental Mindoro

For the calibration of the HEC-HMS model, shown in Figure 56, actual flow discharge during a rainfall event was collected in the Mamburao bridge. Peak discharge is 19.6 cu.m/s on August 6, 2016 at 9:50 pm.

Shown in Figure 57 is the calibration of the model. Peak discharge is 19.6 cu. m/s on August 6, 2016 at 8:30 pm.

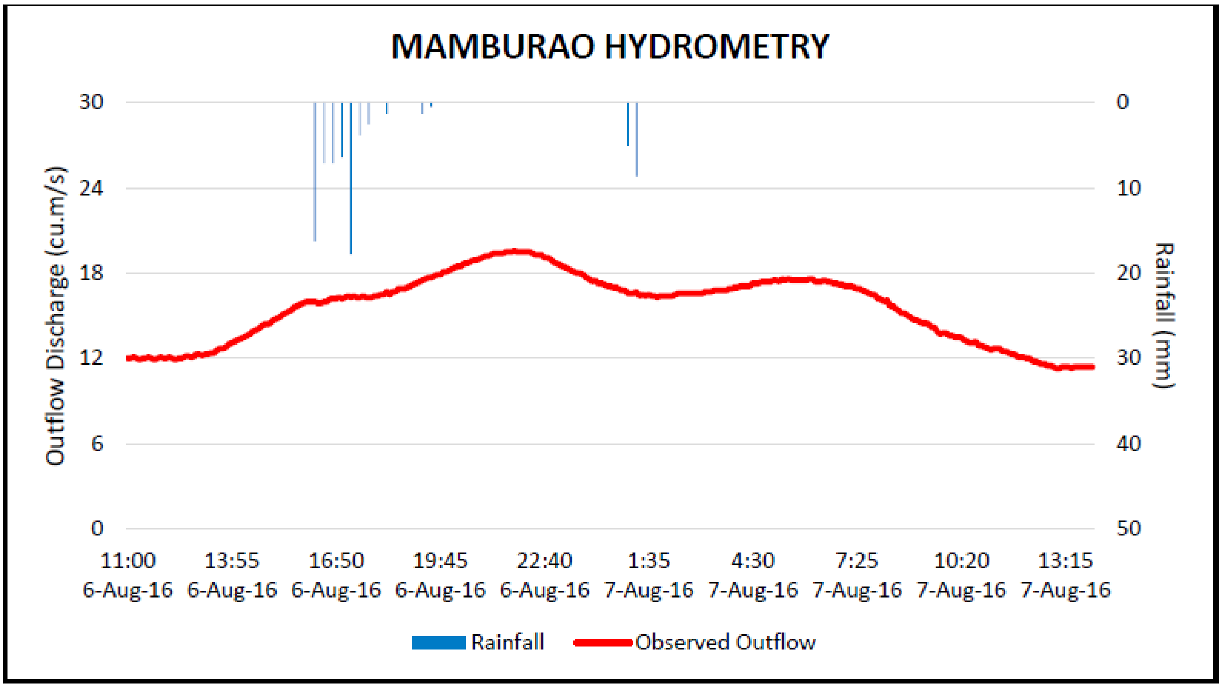


Figure 57. Rainfall and outflow data at Mamburao used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Ambulong Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the values in such a way a certain peak value will be attained at a certain time. This station chosen based on its proximity to the Mamburao watershed. The extreme values for this watershed were computed based on a 54-year record.

Table 26 . RIDF values for Ambulong Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	5 mins	10 mins	15 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	22.7	35.5	36.3	50.2	68.2	80.1	104.1	125.7	150.8
5	27.9	45.5	53.8	74.2	103.4	122.5	159.7	192.9	226.7
10	34.2	52.1	65.4	90.1	126.7	150.6	196.5	237.3	276.9
15	37.8	57.4	71.9	99	139.8	166.4	217.3	262.4	305.3
20	40.3	61	76.5	105.3	149	177.5	231.9	280	325.1
25	42.2	63.9	80	110.1	156.1	186	243.1	293.5	340.4
50	48.1	72.6	90.9	125	178	212.3	277.6	335.2	387.5
100	54	81.2	101.6	139.8	199.7	238.4	311.8	376.6	434.3

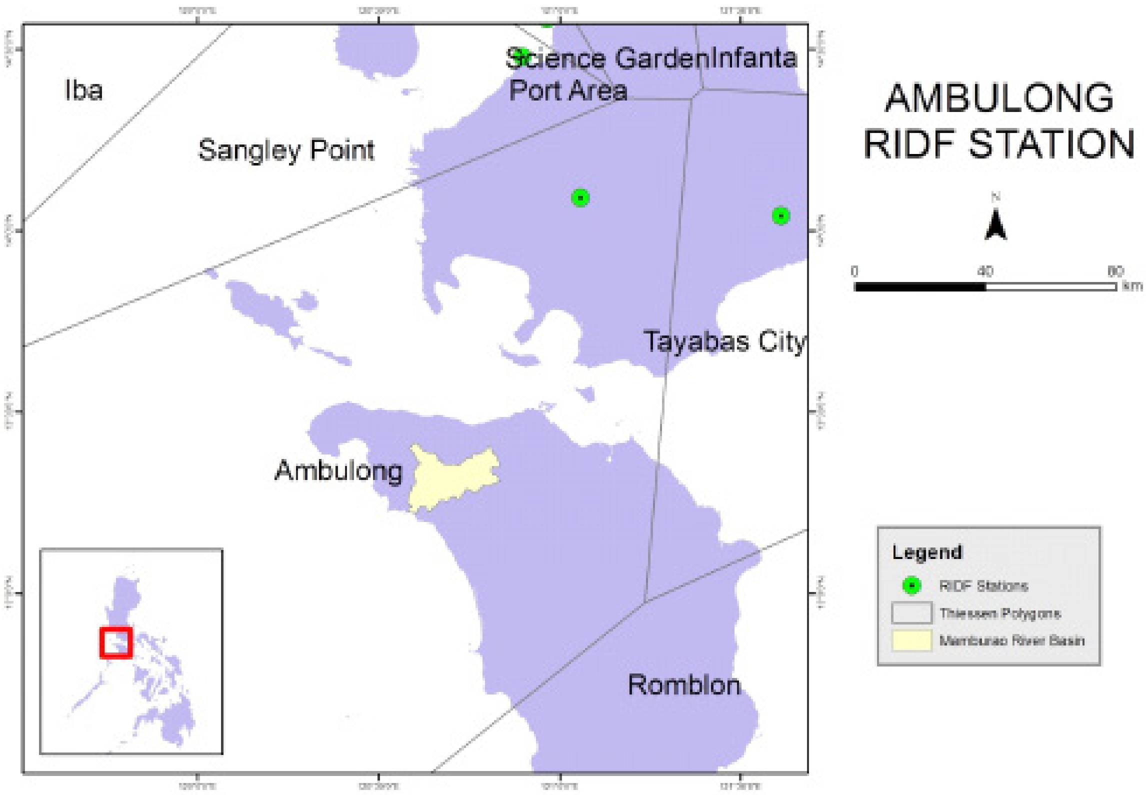


Figure 58. Location of Ambulong RIDF relative to Mamburao River Basin

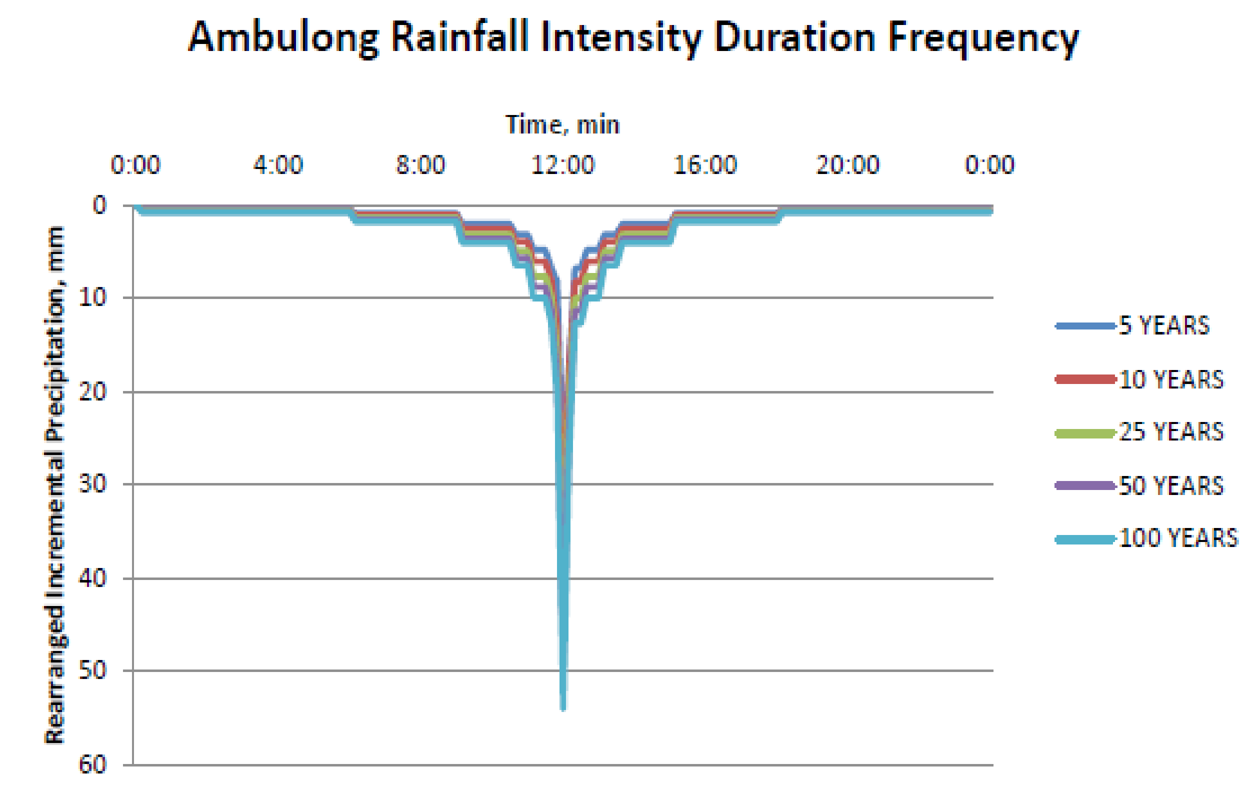


Figure 59. Synthetic Storm Generated For A 24-hr Period Rainfall For Various Return Periods

5.3 HMS Model

The soil shape file (dated pre-2004) was taken from the Bureau of Soils and Water Management under the Department of Agriculture. The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA). The soil map and the land cover map can be found in Annexes 60 and 61, respectively.

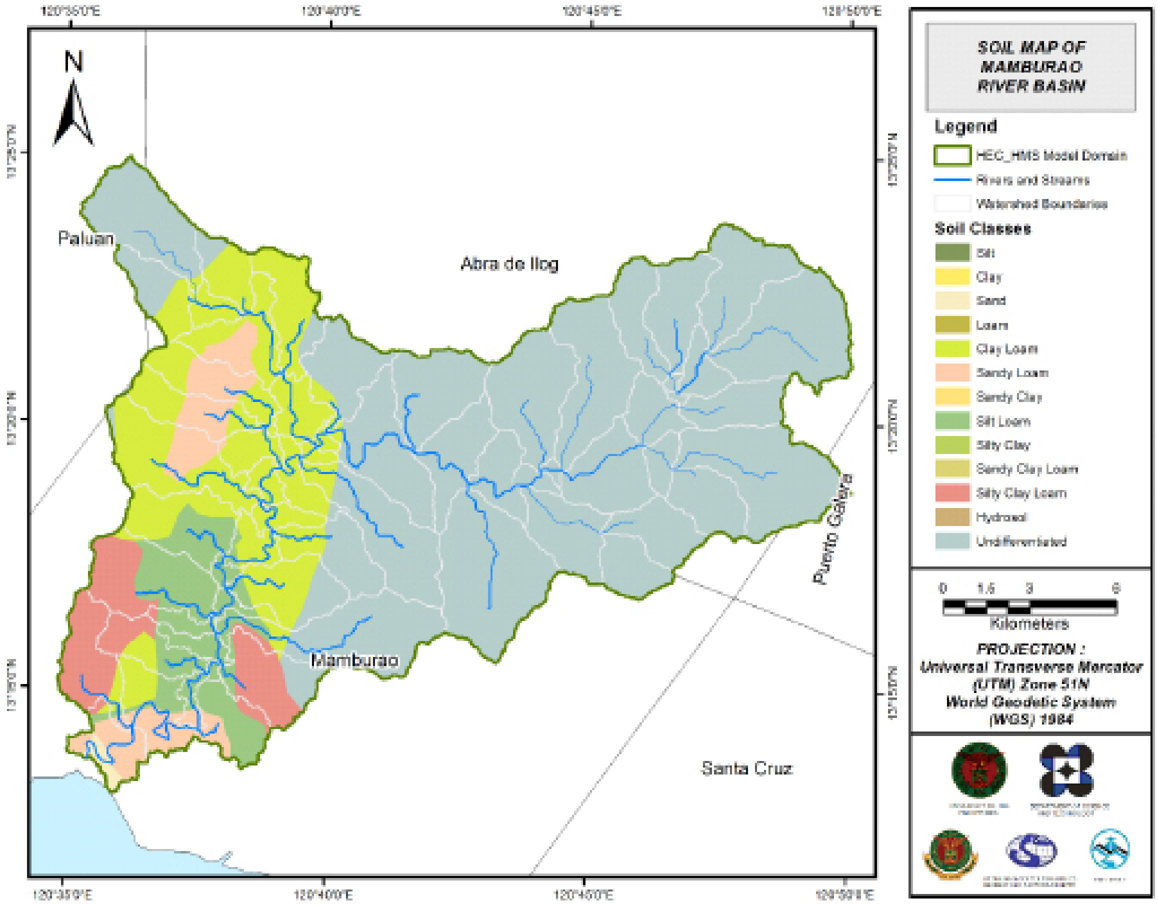


Figure 60. The soil map of the Mamburao River Basin used for the estimation of the CN parameter. (Source of data: Digital soil map of the Philippines published by the Bureau of Soil and Water Management – Department of Agriculture)

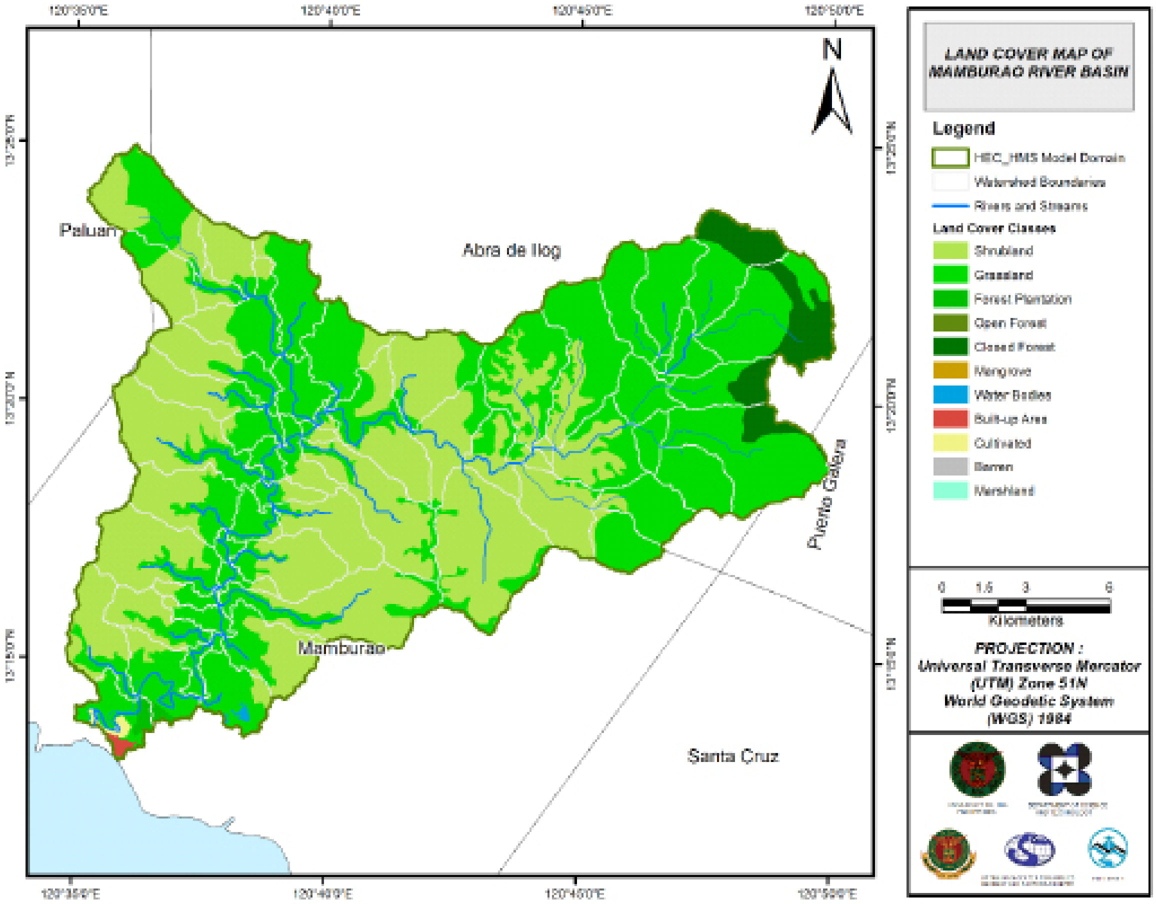


Figure 61. The land cover map of the Mamburao River Basin used for the estimation of the CN and watershed lag parameters of the rainfall-runoff model. (Source: NAMRIA)

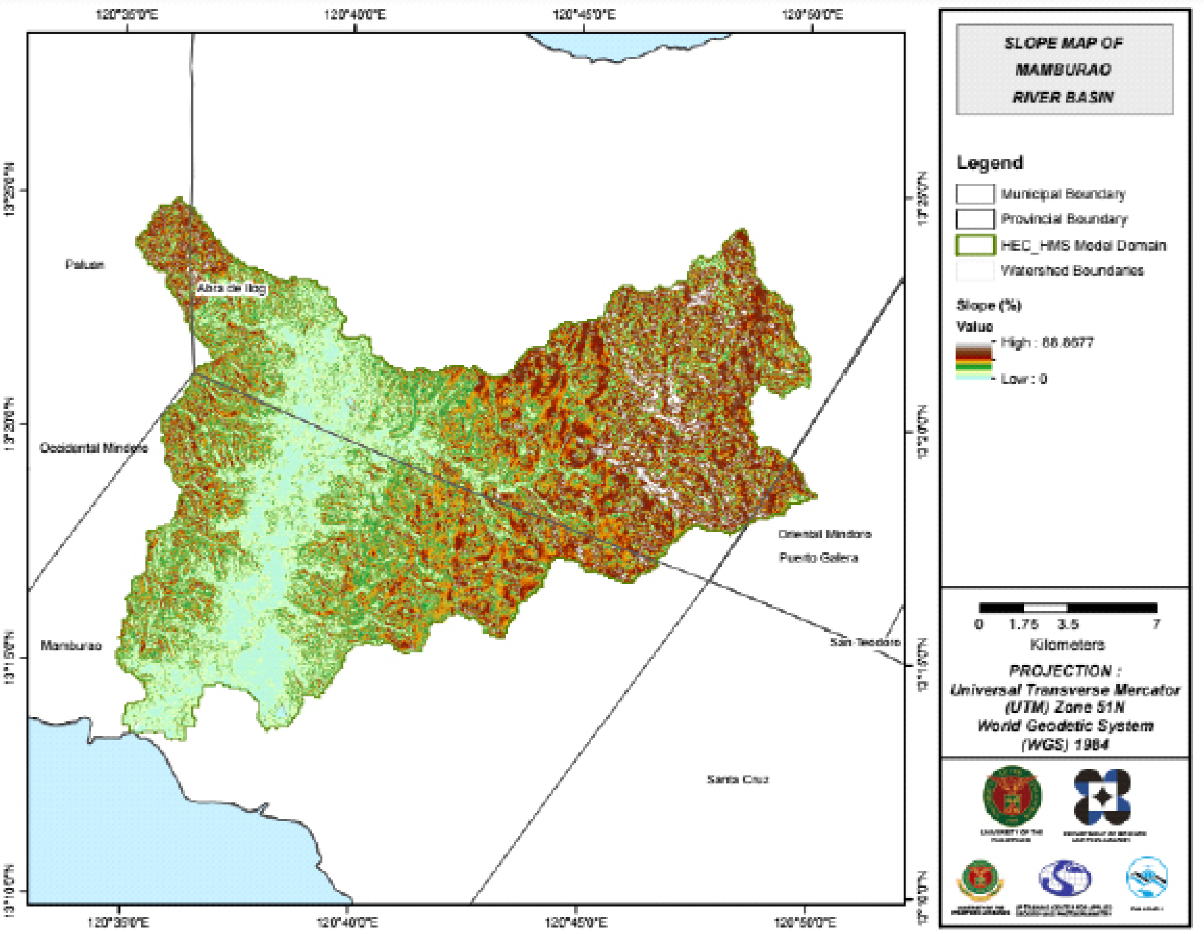


Figure 62. Slope Map of the Mamburao River Basin

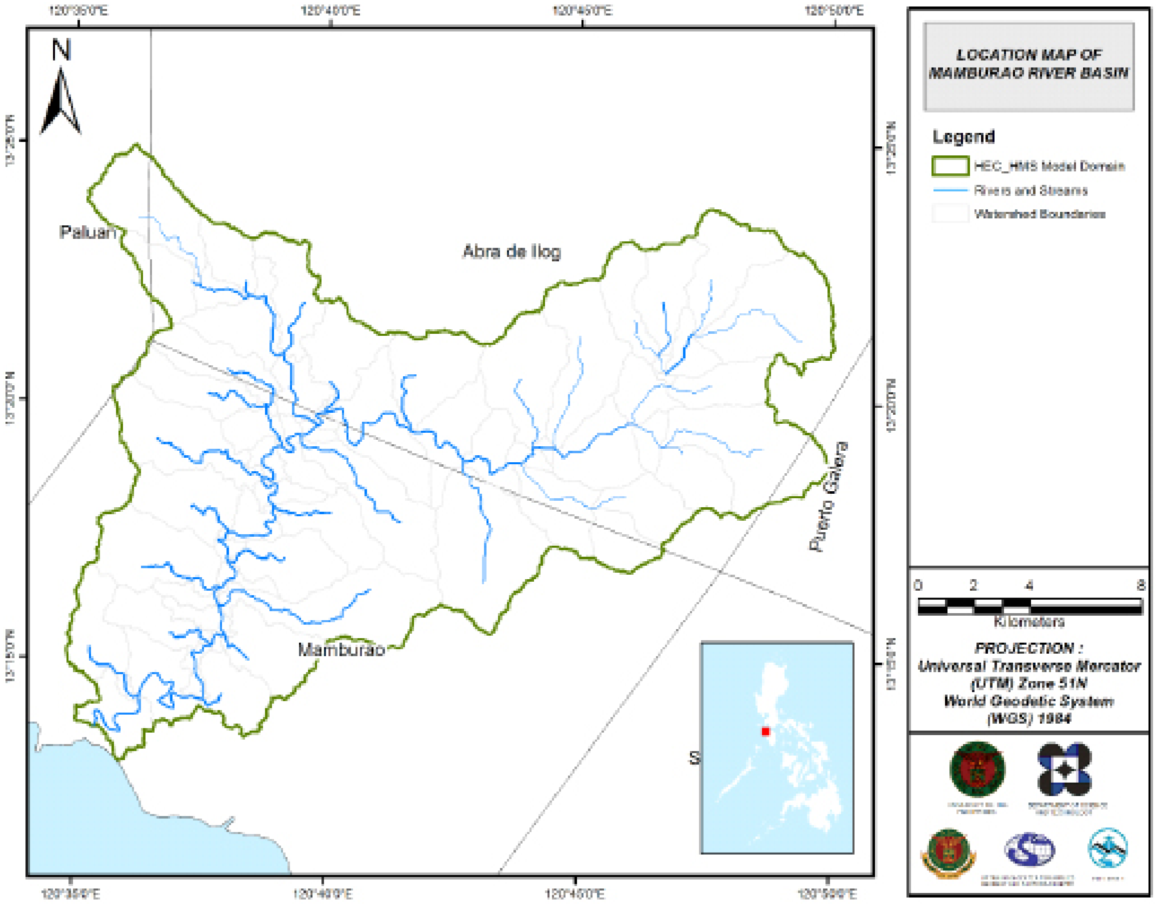


Figure 63. Stream Delineation Map of the Mamburao River Basin

Using SAR-based DEM, the Mamburao basin was delineated and further subdivided into subbasins. The model consists of 60 sub basins, 30 reaches, and 30 junctions. The main outlet is at Mamburao Bridge.

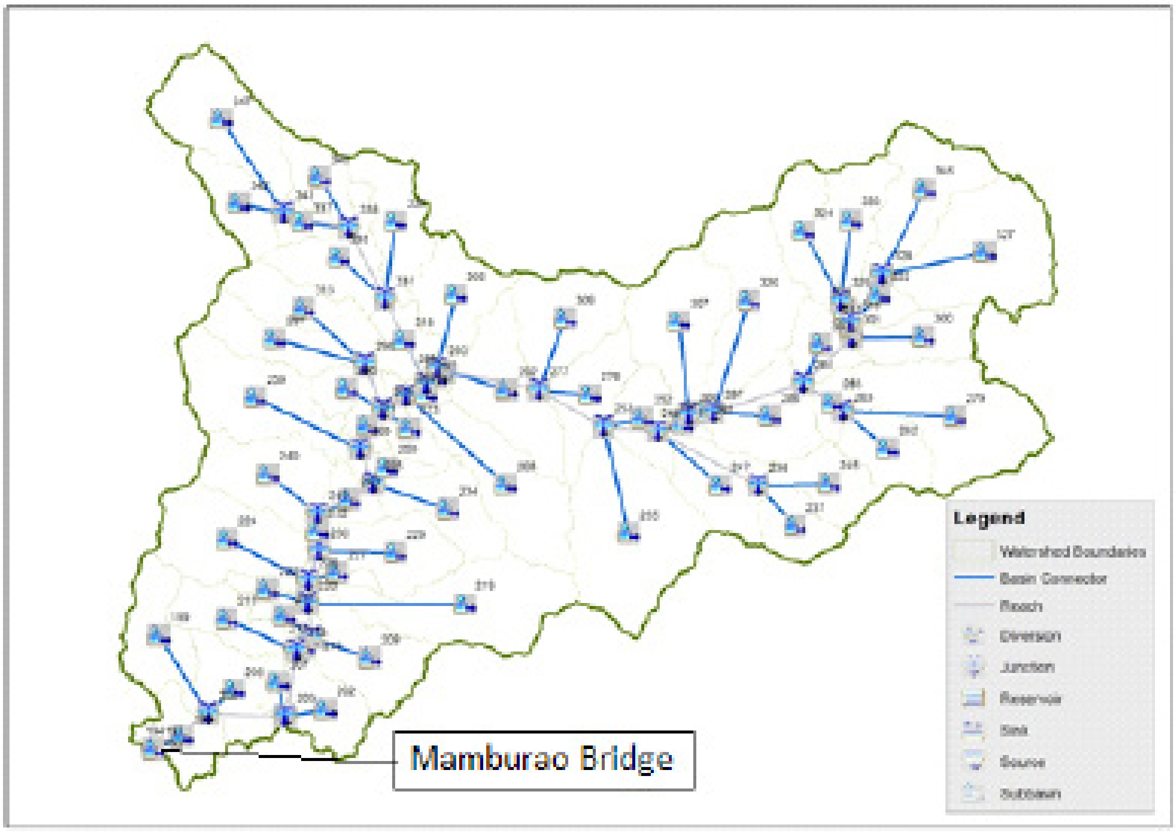


Figure 64. The Mamburao river basin model generated using HEC-HMS

5.4 Cross-section Data

Riverbed cross-sections of the watershed were necessary in the HEC-RAS model setup. The cross-section data for the HEC-RAS model was derived from the LiDAR DEM data. It was defined using the Arc GeoRAS tool and was post-processed in ArcGIS.

Figure 65. River cross-section of the Mamburao River through the ArcMap HEC GeoRas tool

5.5 Flo 2D Model

The automated modelling process allows for the creation of a model with boundaries that are almost exactly coincidental with that of the catchment area. As such, they have approximately the same land area and location. The entire area is divided into square grid elements, 10 meter by 10 meter in size. Each element is assigned a unique grid element number which serves as its identifier, then attributed with the parameters required for modelling such as x-and y-coordinate of centroid, names of adjacent grid elements, Manning coefficient of roughness, infiltration, and elevation value. The elements are arranged spatially to form the model, allowing the software to simulate the flow of water across the grid elements and in eight directions (north, south, east, west, northeast, northwest, southeast, southwest).

Based on the elevation and flow direction, it is seen that the water will generally flow from the north of the model to the south, following the main channel. As such, boundary elements south of the model are assigned as outflow elements.

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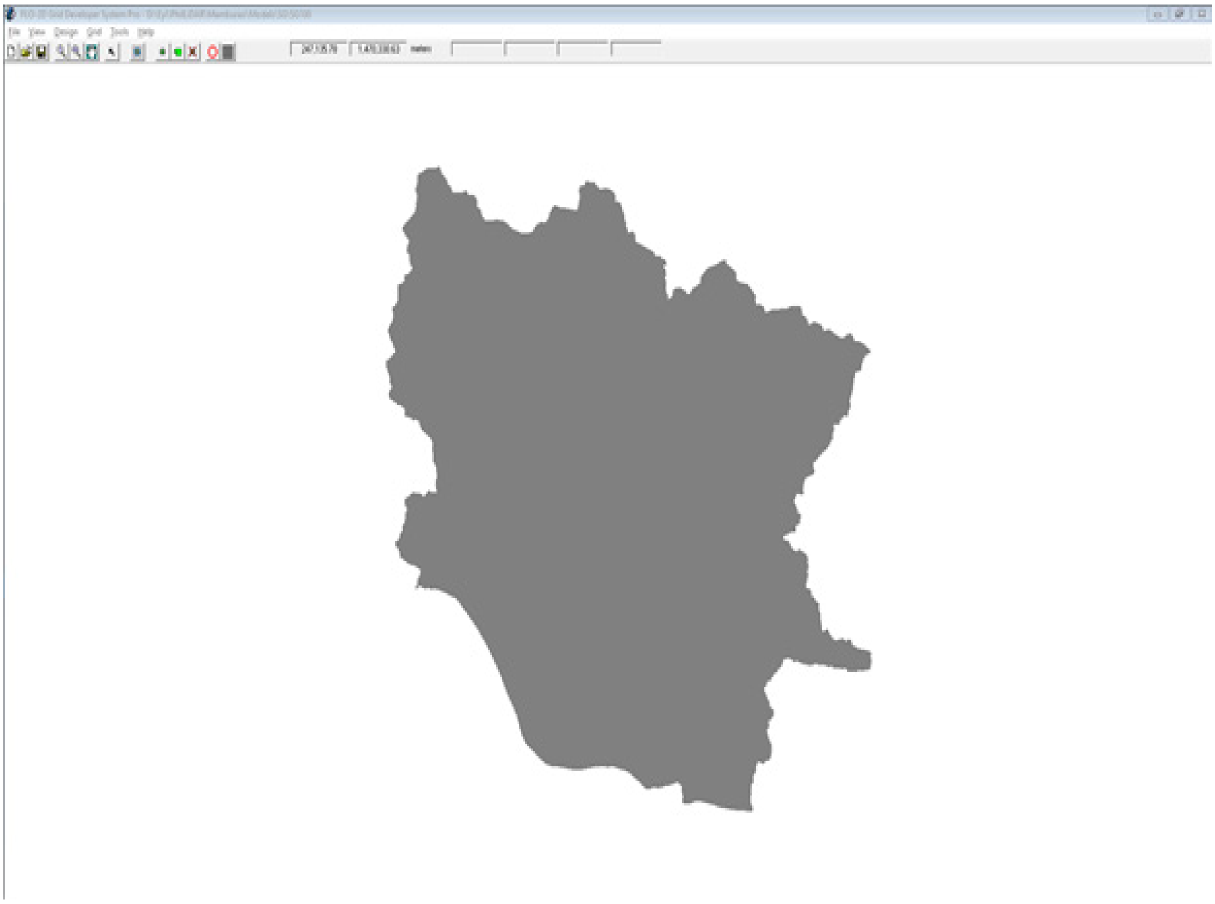

Figure 66. A screenshot of the river sub-catchment with the computational area to be modeled in FLO-2D Grid

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 44.69 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s.

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 59,314,300.00 m2.
There is a total of 82,310,358.10 m3 of water entering the model, of which 24,885,886.04 m3 is due to rainfall and 57,424,472.07 m3 is inflow from basins upstream. 10,474,268.00 m3 of this water is lost to infiltration and interception, while 63,511,316.91 m3 is stored by the flood plain. The rest, amounting up to 8,324,786.85 m3, is outflow.

5.6 Results of HMS Calibration

After calibrating the Mamburao HEC-HMS river basin model, its accuracy was measured against the observed values (see Annex 9: Mamburao Model Basin Parameters). Figure 67 shows the comparison between the two discharge data.

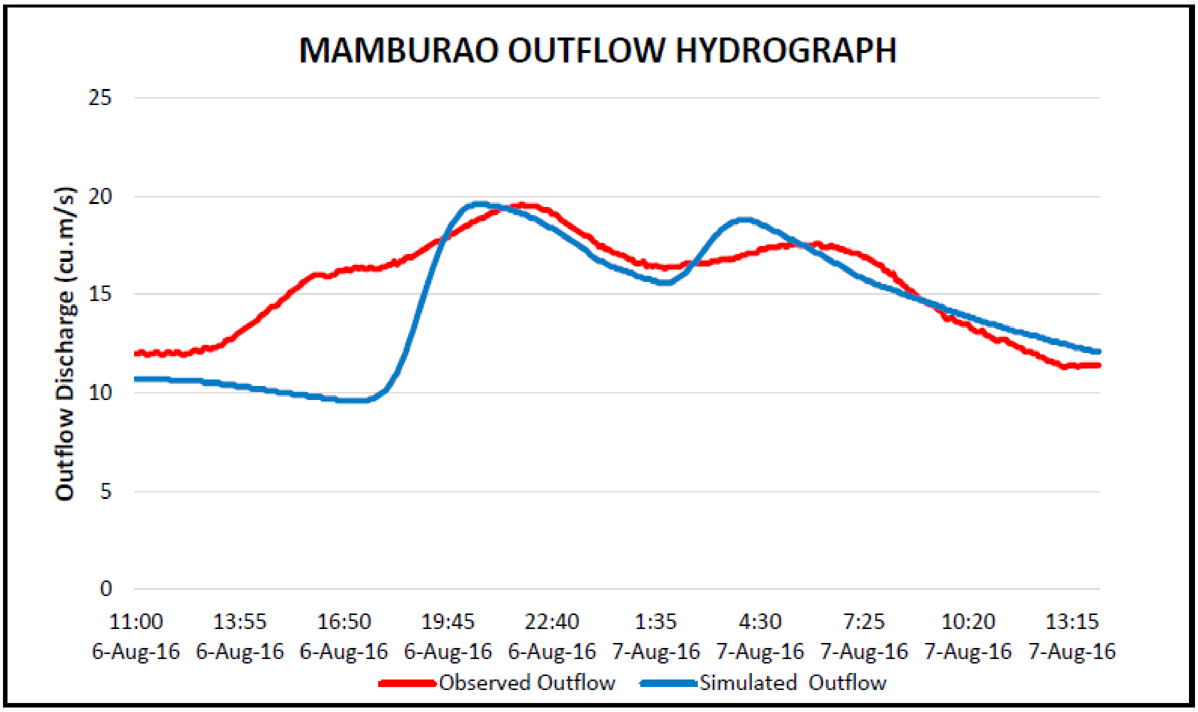

Figure 67. Outflow Hydrograph of Mamburao produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 27 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 27. Range of Calibrated Values for Mamburao

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	4 - 30
			Curve Number	7 - 64
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.07 - 12
			Storage Coefficient (hr)	0.1 - 30
	Baseflow	Recession	Recession Constant	0.5 - 1
			Ratio to Peak	0.3 – 0.5
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.001

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 4 to 30mm means that there is minimal to average amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 7 to 64 for curve number is lower than the advisable range for Philippine watersheds.

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.07 hours to 30 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. Recession constant of 0.5 to 1 indicates that the basin is unlikely to quickly go back to its original discharge and instead, will be higher. Ratio to peak of 0.3 to 0.5 indicates a steeper receding limb of the outflow hydrograph.

Manning's roughness coefficient of 0.001 is relatively low compared to the common roughness of watersheds (Brunner, 2010).

Table 28. Summary of the Efficiency Test of Mamburao HMS Model

Accuracy Measure	Value
Root Mean Square Error (RMSE)	2.544
Pearson Correlation Coefficient (r^2)	0.719
Nash-Sutcliffe (E)	-0.117
Percent Bias (PBIAS)	7.309
Observation Standard Deviation Ratio (RSR)	1.057

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 2.544.

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.719.

The Nash-Sutcliffe (E) method was also used to assess the predictive power of the model. Here the optimal value is 1. The model attained an efficiency coefficient of -0.117.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is 7.309.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable a quantified. The model has an RSR value of 1.057.

5.7 Calculated Outflow hydrographs and Discharge Values for different Rainfall Return Periods

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 68) shows the Mamburao outflow using the Ambulong Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

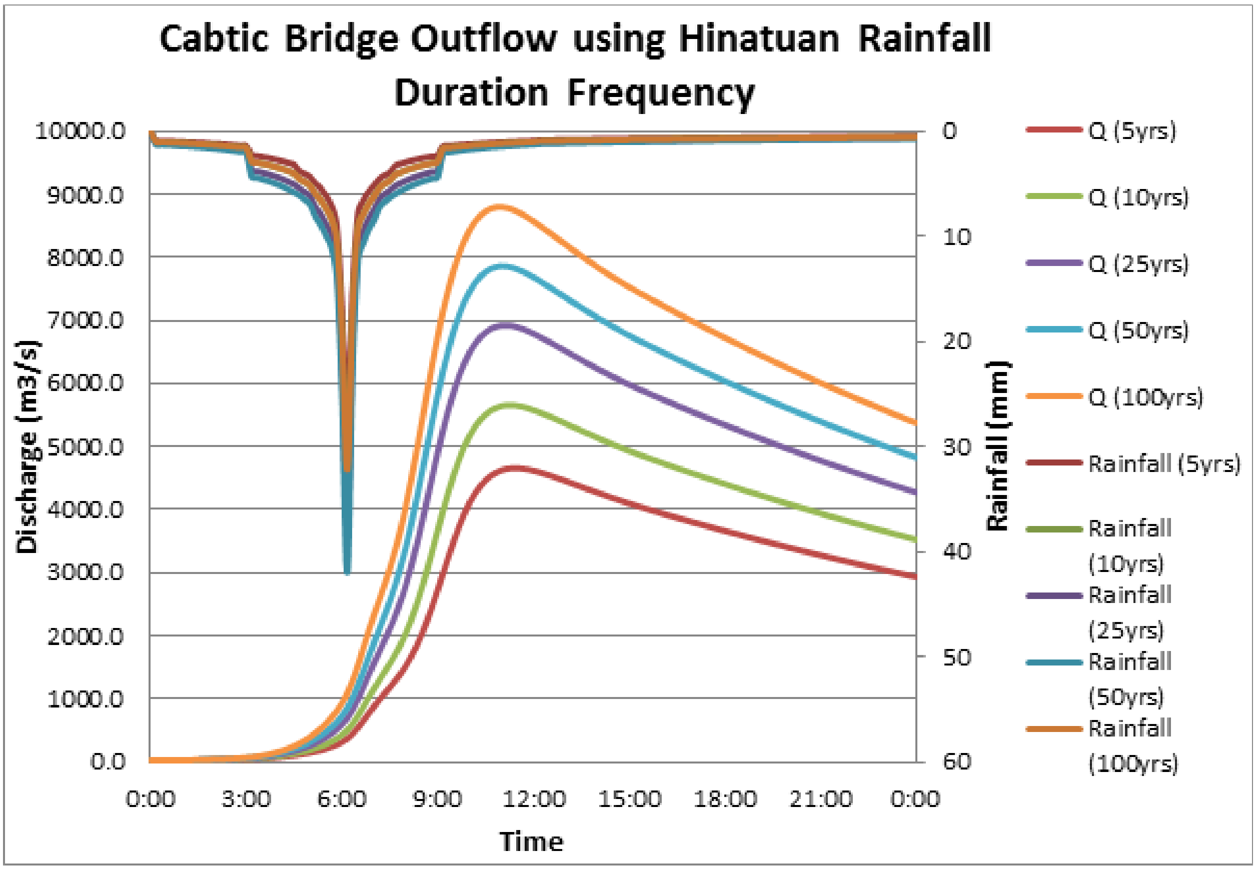

Figure 68. Outflow hydrograph at Mamburao Station generated using Ambulong RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow, time to peak and lag time of the Mamburao discharge using the Ambulong Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods is shown in Table 29.

Table 29. Peak values of the Mamburao HECHMS Model outflow using the Ambulong RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow	Time to Peak	Lag Time
2-Year	226.70	27.90	103.793	17 hours	5 hours
5-Year	276.90	34.20	148.162	17 hours	5 hours
10-Year	340.40	42.20	214.113	17 hours	5 hours
25-Year	387.50	48.10	263.837	17 hours	5 hours
50-Year	434.30	54.0	329.936	16 hours 50 minutes	4 hours 50 minutes
100-Year	483.1	46.11	8799.9	8799.9	5 hours

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. The sample map of Mamburao River using the HMS base flow is shown on Figure 69.

Figure 69. Mamburao HEC-RAS Output

5.9 Flood Hazard and Flow Depth Map

The resulting hazard and flow depth maps for 5-, 25-, and 100-year rain return scenarios of the Mamburao floodplain are shown in Figure 70 to 75. The floodplain, with an area of 221.53 sq. km., covers two municipalities namely Abra de Ilog, and Mamburao. Table 30 shows the percentage of area affected by flooding per municipality.

Table 30. Municipalities affected in Mamburao floodplain

City / Municipality	Total Area	Area Flooded	% Flooded
Abra de Ilog	523.87	41.56	7.93
Mamburao	344.99	179.50	52.03

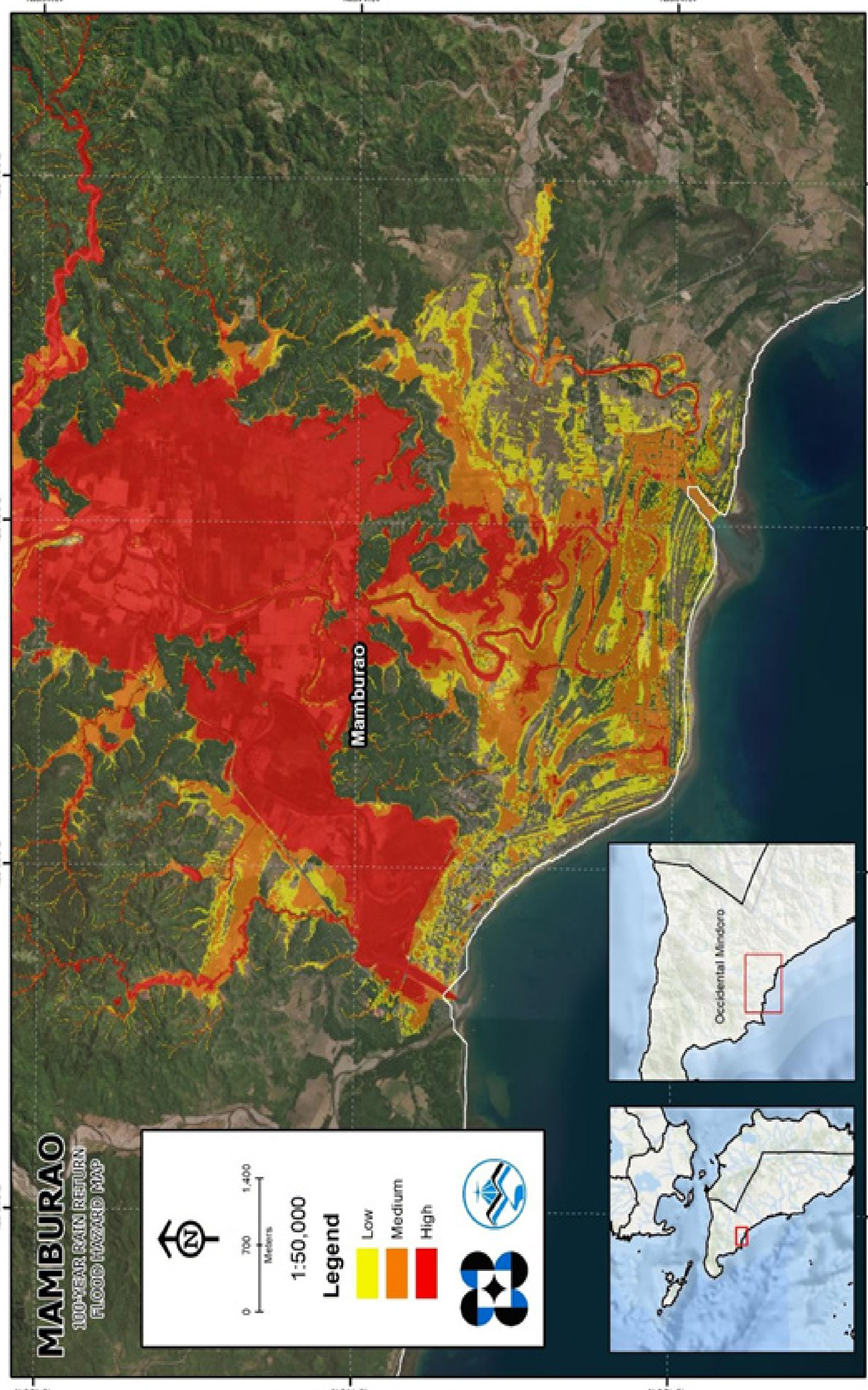

Figure 70. 100-year Flood Hazard Map for Mamburao Floodplain

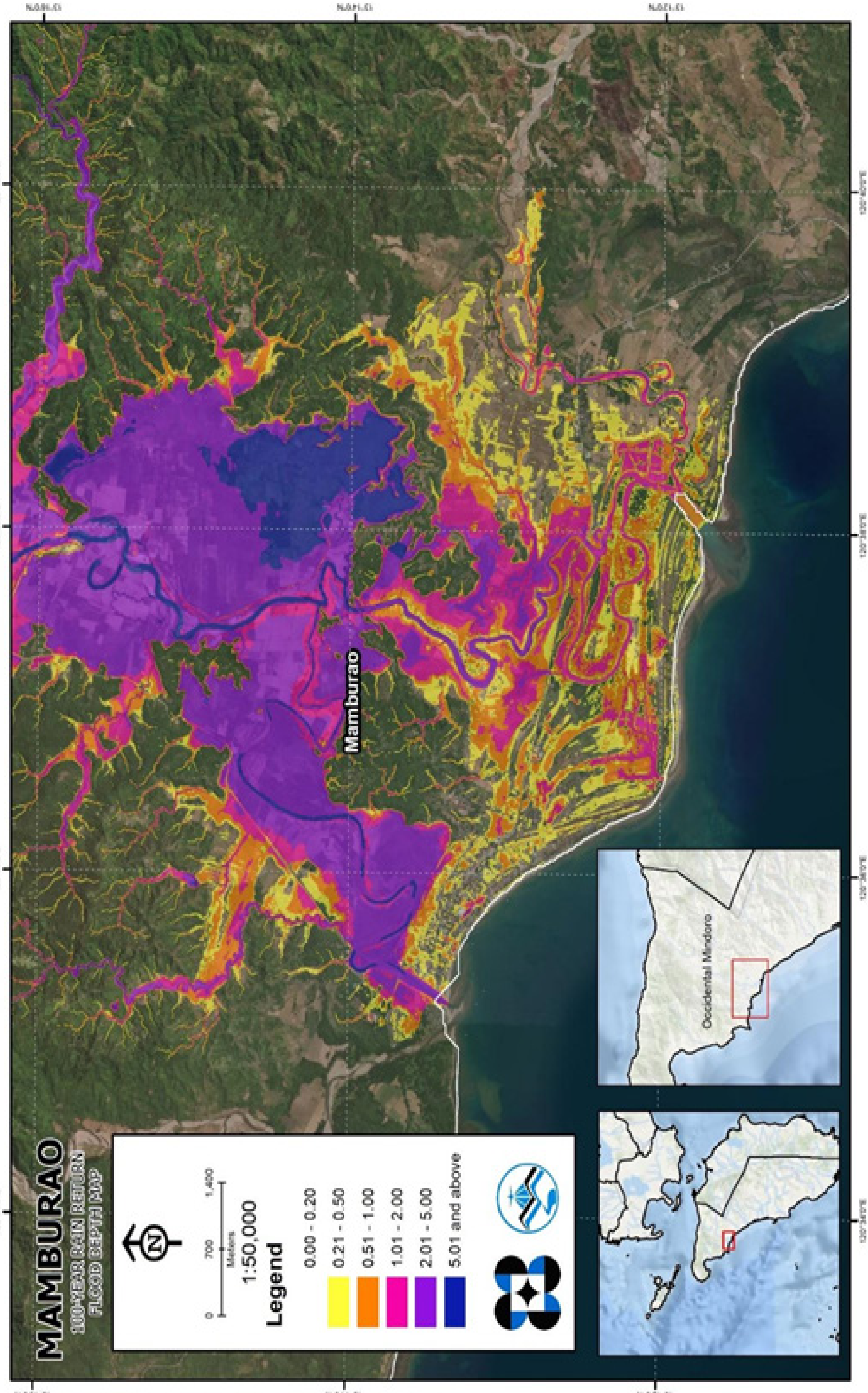

Figure 71. 100-year Flow Depth Map for Mamburao Floodplain

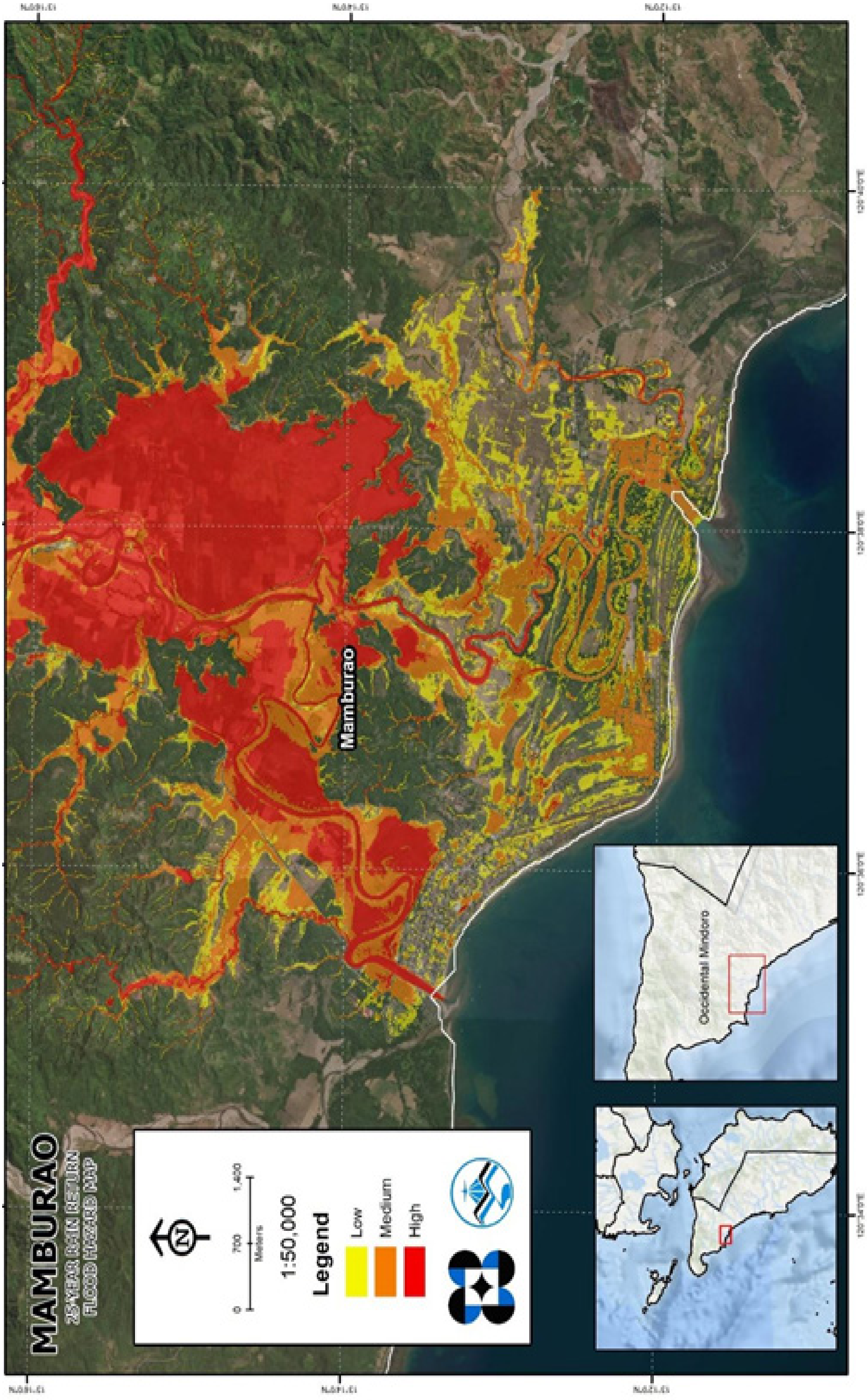

Figure 72. 25-year Flood Hazard Map for Mamburao Floodplain

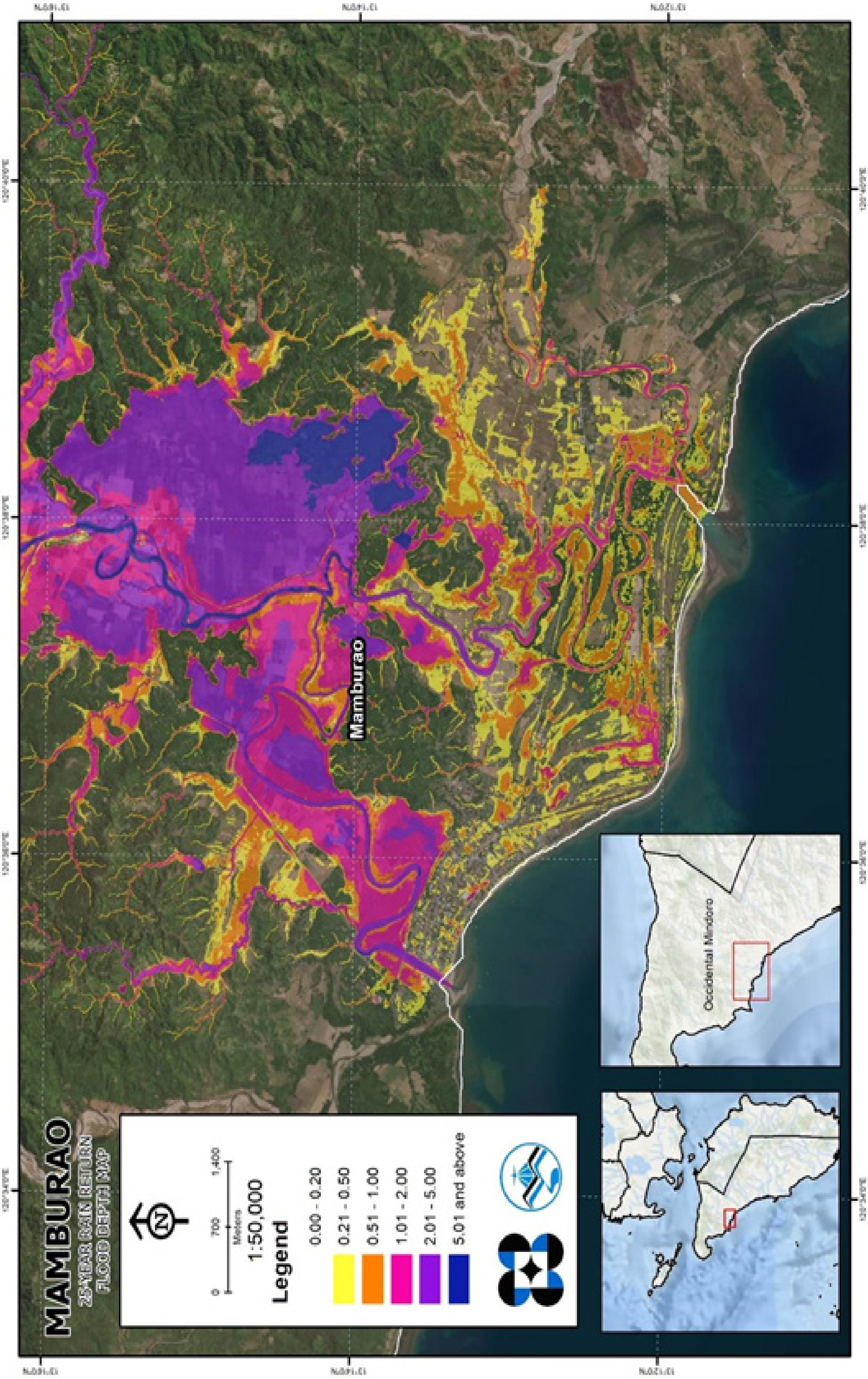

Figure 73. 25-year Flow Depth Map for Mamburao Floodplain

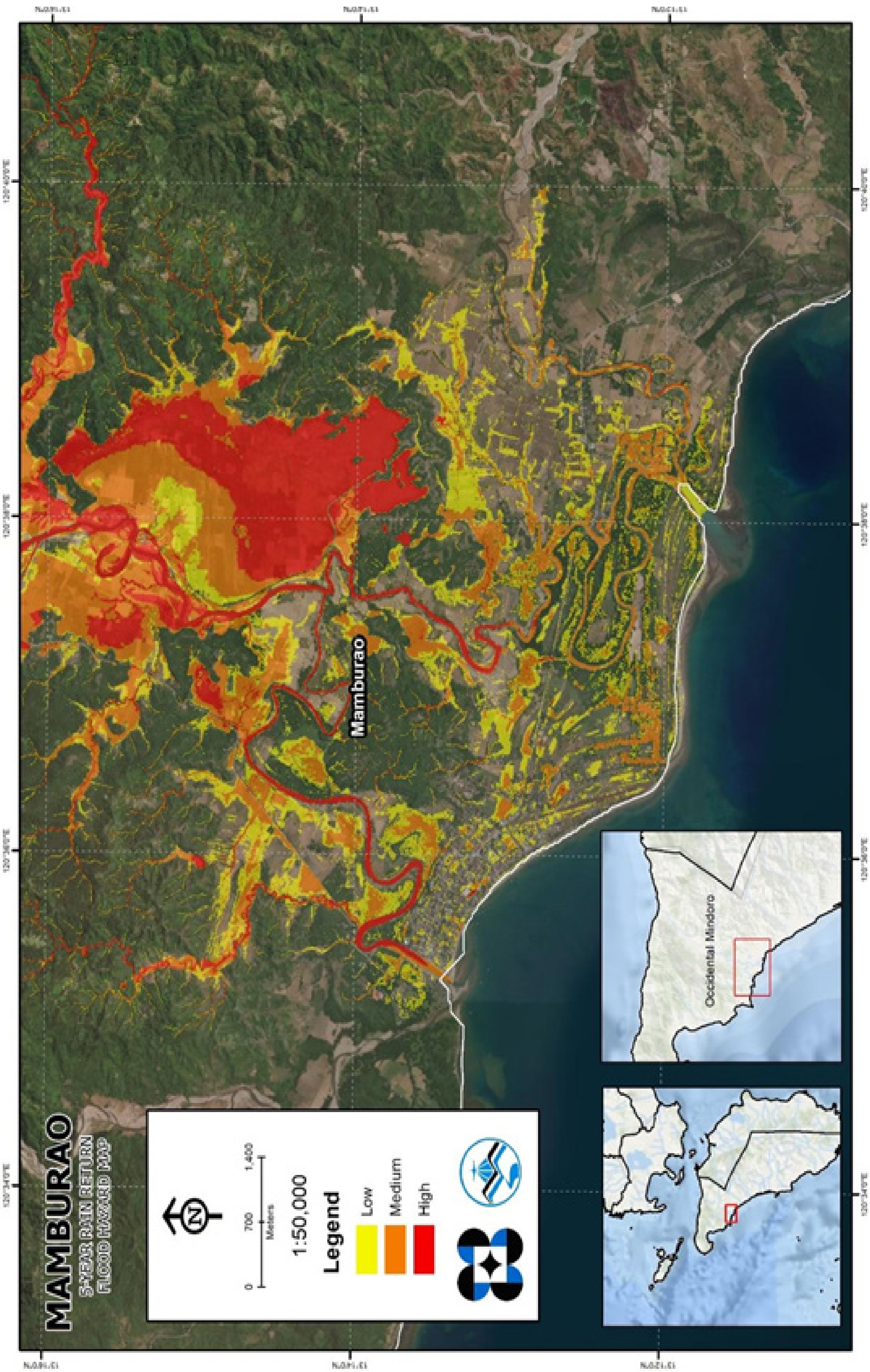

Figure 74. 5-year Flood Hazard Map for Mamburao Floodplain

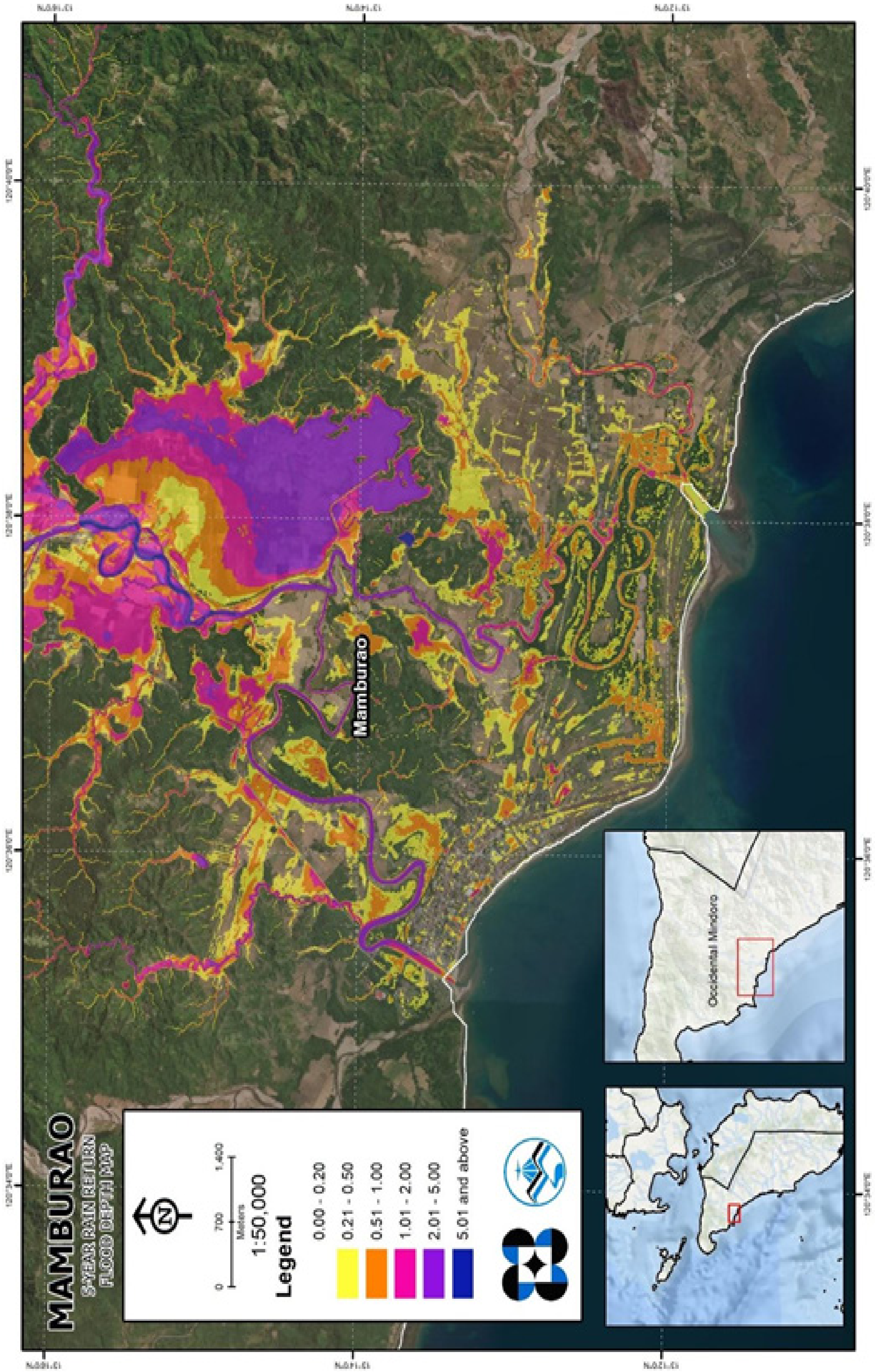

Figure 75. 5-year Flow Depth Map for Mamburao Floodplain

5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Mamburao River Basin, grouped accordingly by municipality. For the said basin, one (2) municipalities consisting of 18 barangays are expected to experience flooding when subjected to a 5-year rainfall return period.

For the 5-year return period, 5.54% of the municipality of Abra de Ilog with an area of 523.87 sq. km. will experience flood levels of less 0.20 meters, while 0.56% of the area will experience flood levels of 0.21 to 0.50 meters; 0.49%, 0.54%, 0.72%, and 0.08% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 t0 5 meters, and more than 5 meters respectively. Table 31 depicts the areas affected in Abra de Ilog in square kilometers by flood depth per barangay.

Table 31. Affected areas in Abra de Ilog, Occidental Mindoro during a 5-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Abra de Ilog		
	Armado	**Cabacao**	**San Vicente**
0.03-0.20	25.00716	2.819165	1.189093
0.21-0.50	2.83304	0.087322	0.033197
0.51-1.00	2.519542	0.037149	0.026546
1.01-2.00	2.801687	0.017074	0.028512
2.01-5.00	3.770064	0.008855	0.019032
> 5.00	0.330929	0.065104	0

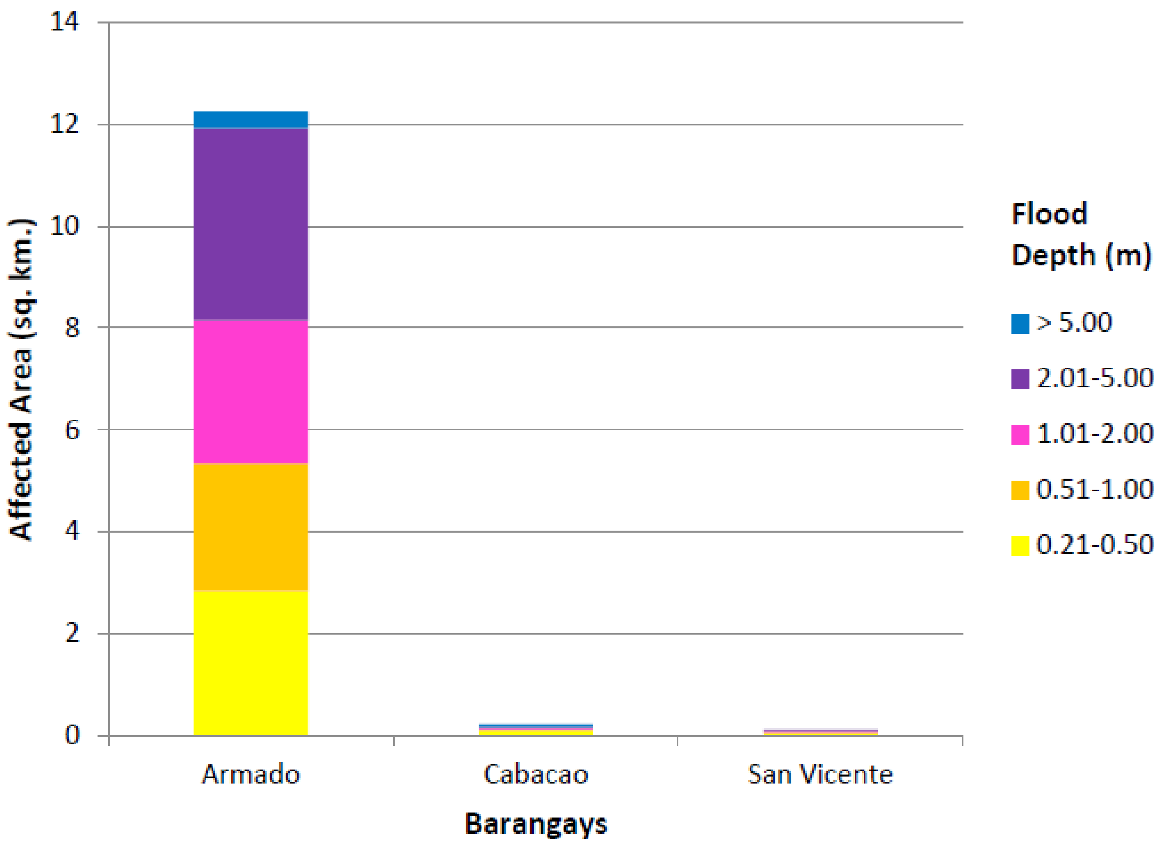

Figure 76. Affected areas in Abra de Ilog, Occidental Mindoro during a 5-Year Rainfall Return Period.

For the municipality of Mamburao, with an area of 344.99 sq. km., 35.93% will experience flood levels of less 0.20 meters. 4.15% of the area will experience flood levels of 0.21 to 0.50 meters while 3.99%, 3.88%, 3.80%, and 0.31% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Tables 32-33 depicts the affected areas in square kilometers by flood depth per barangay.

Table 32. Affected areas in Mamburao, Occidental Mindoro during a 5-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Mamburao						
	Balansay	**Fatima**	**Payompon**	**Poblacion 1**	**Poblacion 2**	**Poblacion 3**	**Poblacion 4**
0.03-0.20	50.19374	26.42593	6.182158	0.168185	0.18594	0.299009	0.189319
0.21-0.50	5.547735	1.748095	1.411701	0.060091	0.015201	0.079066	0.043053
0.51-1.00	5.096401	1.800838	0.802646	0.014369	0.003065	0.015842	0.021485
1.01-2.00	4.810208	1.481317	0.171916	0.006448	0.000333	0.0001	0.006973
2.01-5.00	6.286123	1.445727	0.144236	0	0	0	0.000062
> 5.00	0.478237	0.021408	0.0002	0	0	0	0

Table 33. Affected areas in Mamburao, Occidental Mindoro during a 5-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Mamburao							
	Poblacion 5	**Poblacion 6**	**Poblacion 7**	**Poblacion 8**	**San Luis**	**Talabaan**	**Tangkalan**	**Tayamaan**
0.03-0.20	0.143357	0.245817	0.303146	0.936105	16.57813	4.232076	16.52349	1.346937
0.21-0.50	0.018798	0.083138	0.080538	0.361853	2.090626	0.087795	2.450553	0.243022
0.51-1.00	0.009514	0.030356	0.039247	0.204127	2.156309	0.058989	3.010732	0.515115
1.01-2.00	0.002291	0.018478	0.02855	0.014328	2.294165	0.088997	3.482115	0.988327
2.01-5.00	0.0105	0.042704	0.003864	0.062303	1.269194	0.143057	3.006966	0.67777
> 5.00	0	0.0005	0	0	0.132739	0.008427	0.435671	0.0009

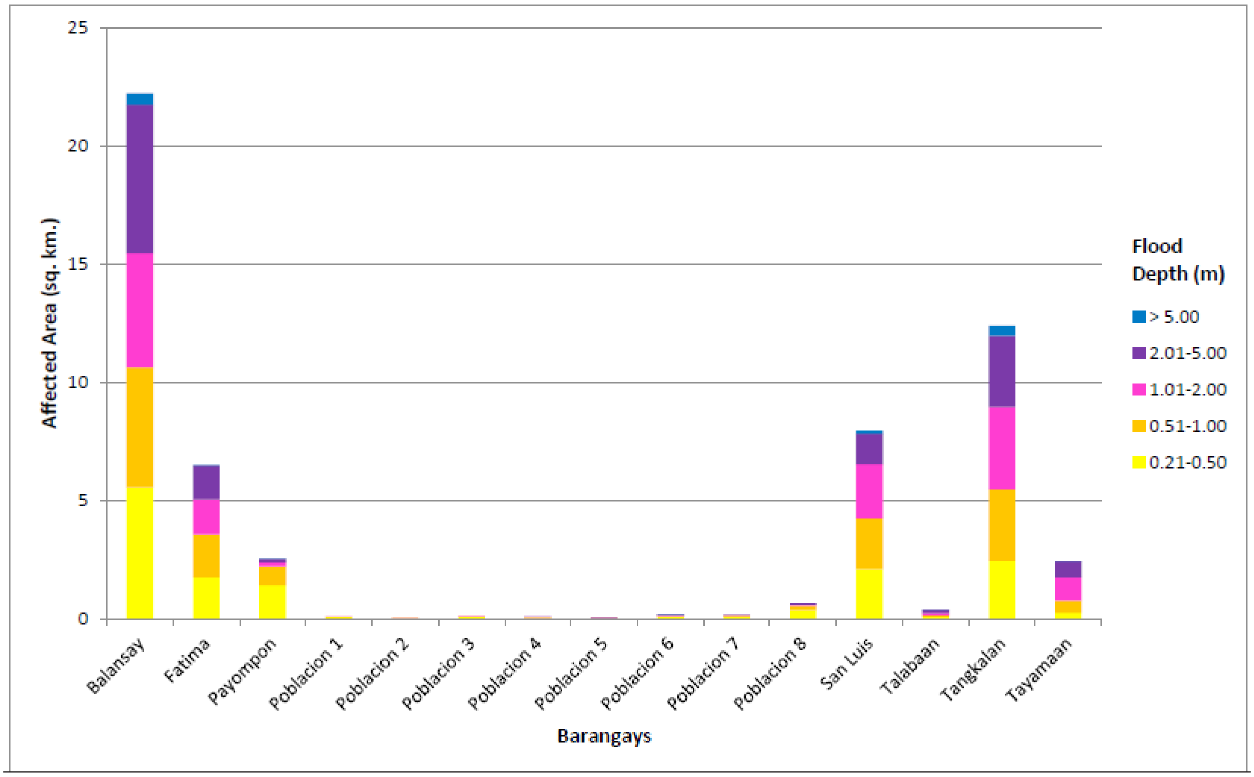

Figure 77. Areas affected by flooding in Mamburao, Occidental Mindoro for a 5-Year Return Period rainfall event.

For the 25-year return period, 5.23% of the municipality of Abra de Ilog with an area of 523.87 sq. km. will experience flood levels of less 0.20 meters, while 0.44% of the area will experience flood levels of 0.21 to 0.50 meters; 0.60%, 0.57%, 0.85%, and 0.25% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 t0 5 meters, and more than 5 meters respectively. Table 34 depicts the areas affected in Abra de Ilog in square kilometers by flood depth per barangay.

Table 34. Affected areas in Abra de Ilog, Occidental Mindoro during a 25-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	**Affected Barangays in Abra de Ilog**		
	Armado	**Cabacao**	**San Vicente**
0.03-0.20	23.46925	2.778812	1.173944
0.21-0.50	2.159164	0.102984	0.035061
0.51-1.00	3.075603	0.047989	0.025917
1.01-2.00	2.944771	0.023197	0.032058
2.01-5.00	4.389903	0.012283	0.029498
> 5.00	1.227977	0.069454	0

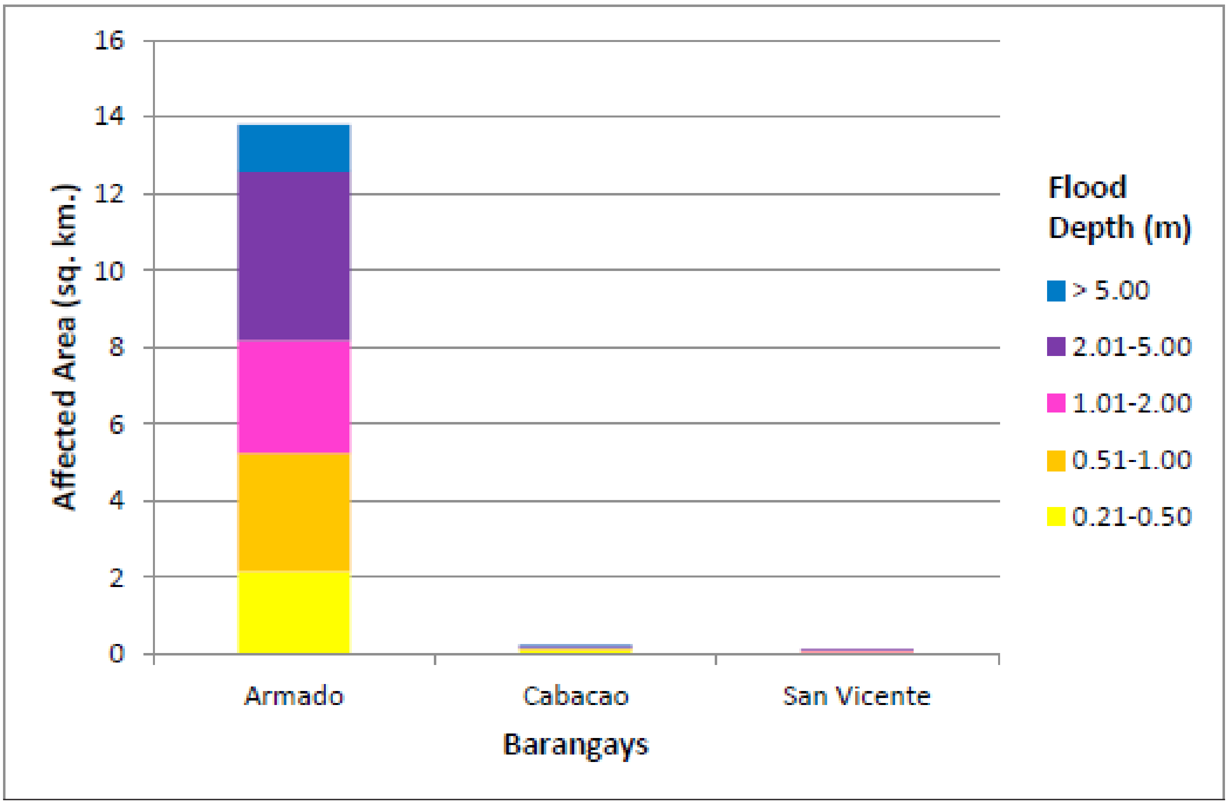

Figure 78. Affected areas in Abra de Ilog, Occidental Mindoro during a 25-Year Rainfall Return Period.

For the municipality of Mamburao, with an area of 344.99 sq. km., 33.11% will experience flood levels of less 0.20 meters. 3.52% of the area will experience flood levels of 0.21 to 0.50 meters while 3.66%, 4.69%, 6.09%, and 0.99% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Tables 35-36 depicts the affected areas in square kilometers by flood depth per barangay.

Table 35. Affected areas in Mamburao, Occidental Mindoro during a 25-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	**Affected Barangays in Mamburao**						
	Balansay	**Fatima**	**Payompon**	**Poblacion 1**	**Poblacion 2**	**Poblacion 3**	**Poblacion 4**
0.03-0.20	46.80807	25.56506	4.305907	0.131951	0.177767	0.262714	0.160229
0.21-0.50	5.108062	1.541336	1.428161	0.088561	0.021939	0.102063	0.045762
0.51-1.00	4.67627	1.802064	1.177221	0.020417	0.00346	0.029105	0.022122
1.01-2.00	4.718604	1.804904	1.311578	0.008164	0.001374	0.000134	0.022887
2.01-5.00	9.13021	2.016274	0.488489	0	0	0	0.009829
> 5.00	1.978324	0.194082	0.0015	0	0	0	0.000062

Table 33. Affected areas in Mamburao, Occidental Mindoro during a 5-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Mamburao							
	Poblacion 5	Poblacion 6	Poblacion 7	Poblacion 8	San Luis	Talabaan	Tangkalan	Tayamaan
0.03-0.20	0.124117	0.126505	0.238611	0.456142	15.0213	4.17826	15.4523	1.233038
0.21-0.50	0.019436	0.028725	0.078159	0.103571	1.325907	0.101921	1.960219	0.196676
0.51-1.00	0.006065	0.040973	0.05402	0.221743	1.525812	0.061543	2.674497	0.310969
1.01-2.00	0.018842	0.157721	0.047267	0.596067	3.122468	0.058292	3.333771	0.986326
2.01-5.00	0.014741	0.061246	0.037288	0.198715	3.283286	0.18403	4.552334	1.035662
> 5.00	0.00126	0.005822	0	0.002477	0.256518	0.035295	0.940276	0.0094

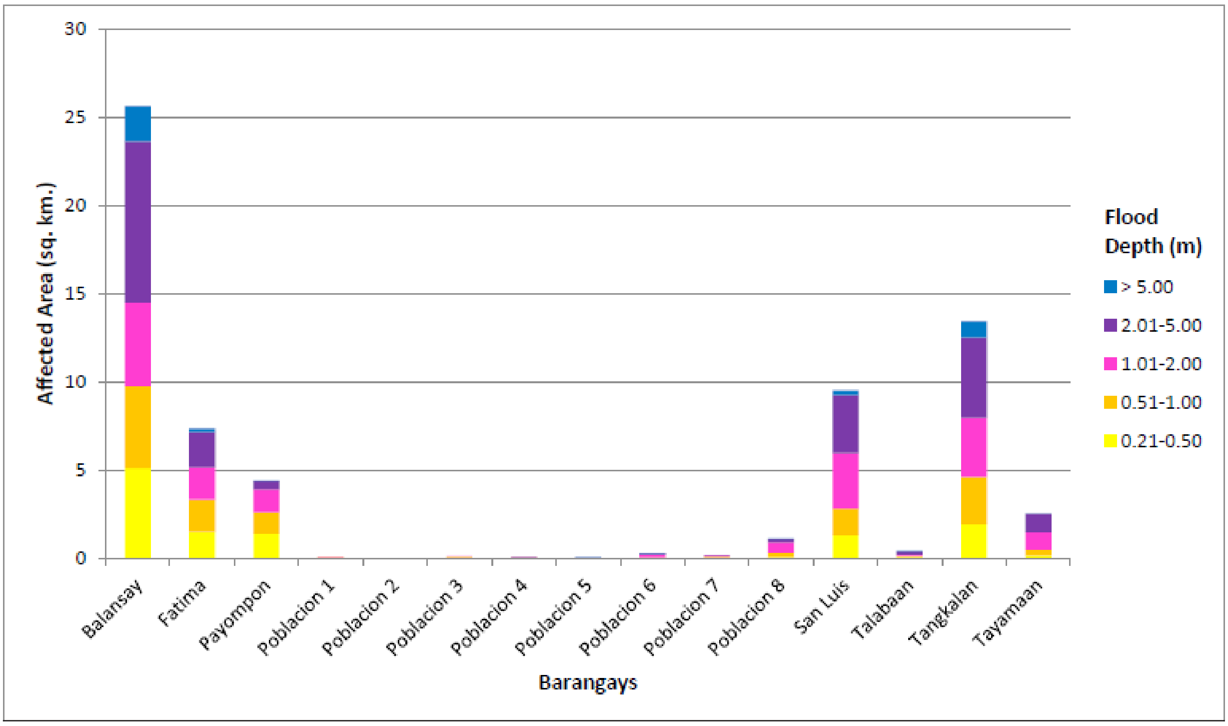

Figure 79. Areas affected by flooding in Mamburao, Occidental Mindoro
for a 25-Year Return Period rainfall event.

For the 100-year return period, 5.10% of the municipality of Abra de Ilog with an area of 523.87 sq. km. will experience flood levels of less 0.20 meters, while 0.35% of the area will experience flood levels of 0.21 to 0.50 meters; 0.57%, 0.66%, 0.85%, and 0.42% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 t0 5 meters, and more than 5 meters respectively. Table 37 depicts the areas affected in Abra de Ilog in square kilometers by flood depth per barangay.

Table 37. Affected areas in Abra de Ilog, Occidental Mindoro during a 100-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Abra de Ilog		
	Armado	**Cabacao**	**San Vicente**
0.03-0.20	22.78542	2.750518	1.162403
0.21-0.50	1.663601	0.112856	0.03797
0.51-1.00	2.881815	0.056303	0.02585
1.01-2.00	3.401945	0.025714	0.031058
2.01-5.00	4.402641	0.017569	0.038698
> 5.00	2.13595	0.071759	0.0005

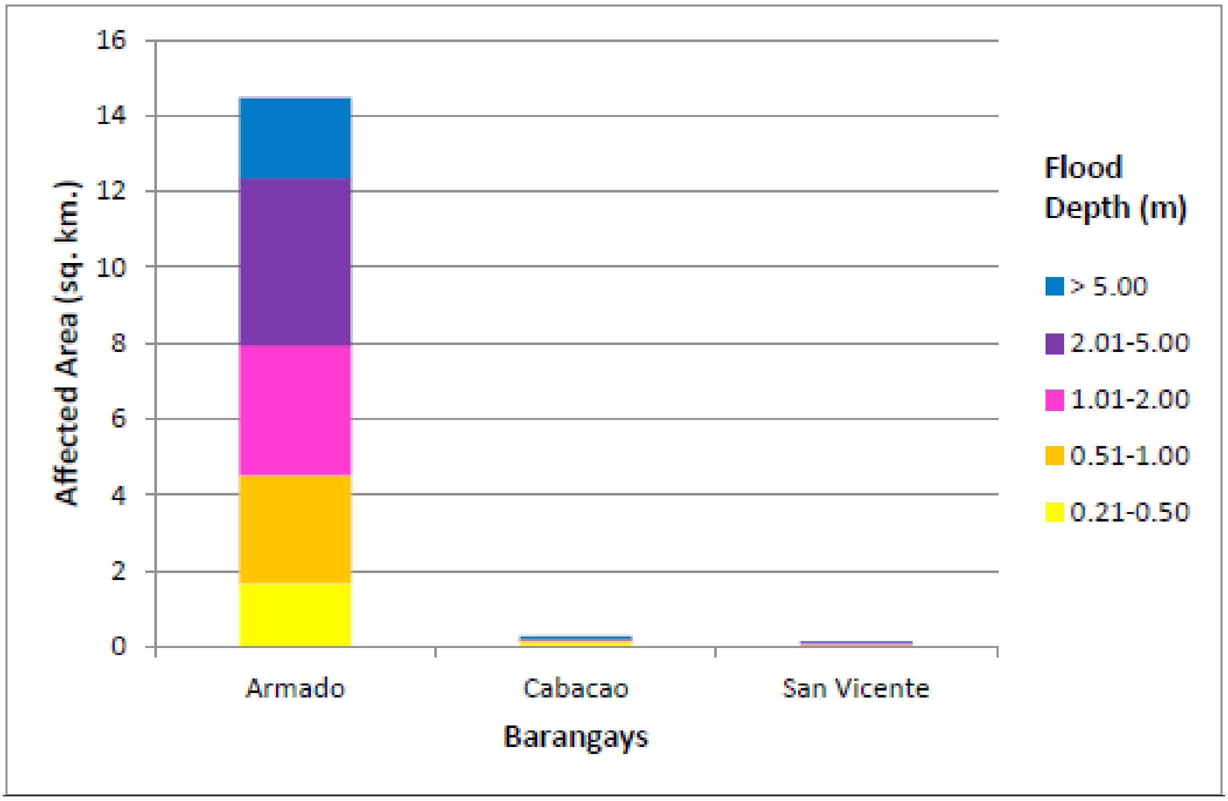

Figure 80. Affected areas in Abra de Ilog, Occidental Mindoro during a 100-Year Rainfall Return Period.

For the municipality of Mamburao, with an area of 344.99 sq. km., 31.41% will experience flood levels of less 0.20 meters. 3.30% of the area will experience flood levels of 0.21 to 0.50 meters while 3.39%, 4.43%, 7.54%, and 2.01% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Tables 38-39 depicts the affected areas in square kilometers by flood depth per barangay.

Table 38. Affected areas in Mamburao, Occidental Mindoro during a 100-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Mamburao						
	Balansay	**Fatima**	**Payompon**	**Poblacion 1**	**Poblacion 2**	**Poblacion 3**	**Poblacion 4**
0.03-0.20	44.26669	25.08039	3.26399	0.112994	0.170643	0.221831	0.117081
0.21-0.50	4.823374	1.449935	1.324057	0.096344	0.027476	0.116666	0.057855
0.51-1.00	4.559756	1.70751	1.316995	0.030192	0.004919	0.04823	0.031566
1.01-2.00	5.613984	2.013435	1.29828	0.009563	0.001503	0.006636	0.02413
2.01-5.00	9.227459	2.251817	1.404638	0	0	0.000653	0.030198
> 5.00	3.933876	0.420736	0.104896	0	0	0	0.000062

Table 39. Affected areas in Mamburao, Occidental Mindoro during a 100-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Mamburao							
	Poblacion 5	**Poblacion 6**	**Poblacion 7**	**Poblacion 8**	**San Luis**	**Talabaan**	**Tangkalan**	**Tayamaan**
0.03-0.20	0.081043	0.051312	0.141401	0.388744	14.38346	4.142941	14.80668	1.141508
0.21-0.50	0.030201	0.036942	0.115802	0.088225	1.247325	0.10946	1.672324	0.174521
0.51-1.00	0.030163	0.047214	0.048967	0.100979	1.392568	0.066686	2.067883	0.243617
1.01-2.00	0.006765	0.053106	0.073074	0.129117	1.733837	0.057979	3.378103	0.897318
2.01-5.00	0.032284	0.206395	0.073911	0.840042	5.349411	0.178122	5.117541	1.287606
> 5.00	0.004005	0.026025	0.000789	0.031609	0.430093	0.064151	1.874066	0.028

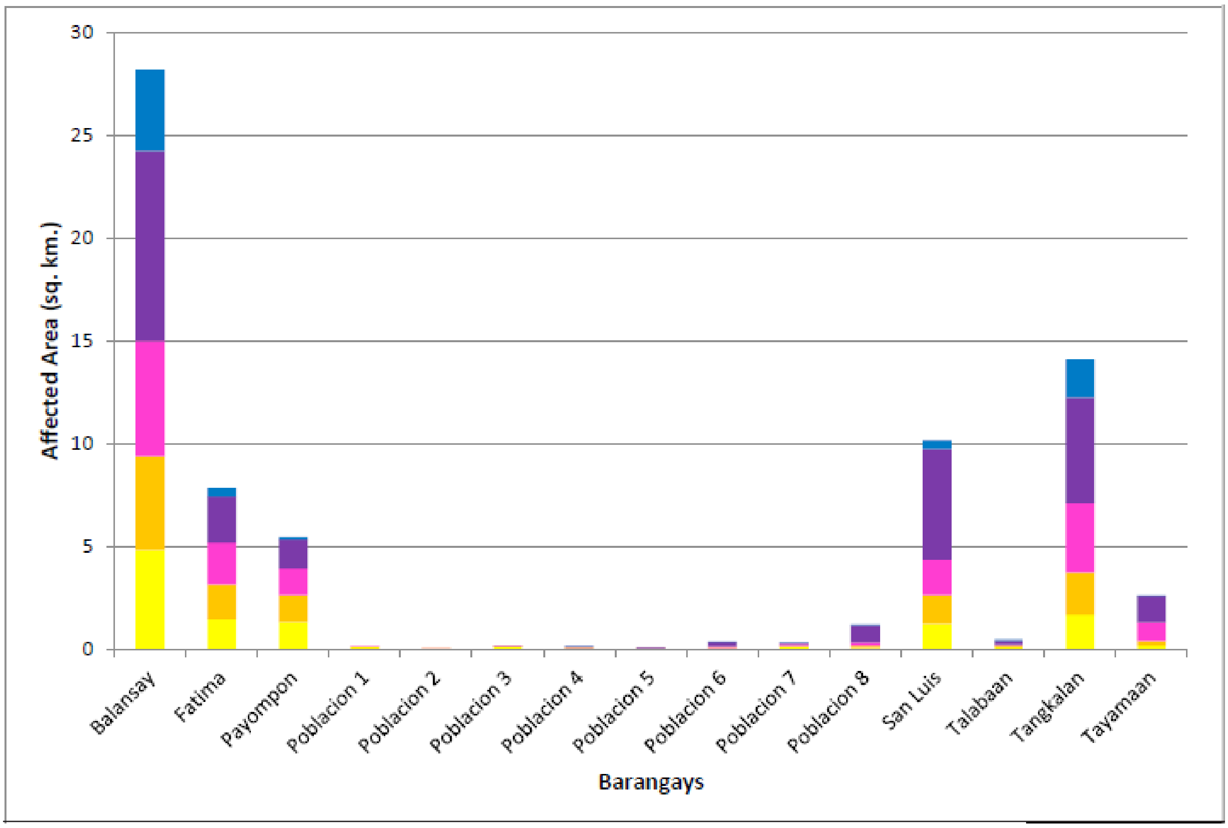

Figure 81. Areas affected by flooding in Mamburao, Occidental Mindoro
for a 100-Year Return Period rainfall event.

Among the barangays in the municipality of Abra de Ilog, Armado is projected to have the highest percentage of area that will experience flood levels of at 7.11%. On the other hand, Cabacao posted the percentage of area that may be affected by flood depths of at 0.58%.

Among the barangays in the municipality of Mamburao, Balansay is projected to have the highest percentage of area that will experience flood levels of at 20.99%. On the other hand, Fatima posted the percentage of area that may be affected by flood depths of at 9.54%.

5.11 Flood Validation

In order to check and validate the extent of flooding in different river systems, a validation survey work was performed. Field personnel gathered data regarding flood occurrence in the area within the major river system in the Philippines.

From the Flood Depth Maps produced by Phil-LiDAR 1 Program, multiple points representing the different flood depths for different scenarios were identified for validation.

The validation personnel went to the specified points identified in a river basin and gathered data regarding the actual flood level in each location. Data gathering was done through the help of a local DRRM office to obtain maps or situation reports about the past flooding events and through interviews of some residents with knowledge of or have had experienced flooding in a particular area.

After which, the actual data from the field were compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed. The points in the flood map versus its corresponding validation depths are shown in Figure 82.

The flood validation consists of 153 points randomly selected all over the Mamburao flood plain. Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 0.862m. Table 40 shows a contingency matrix of the comparison. The validation points are found in Annex 11.

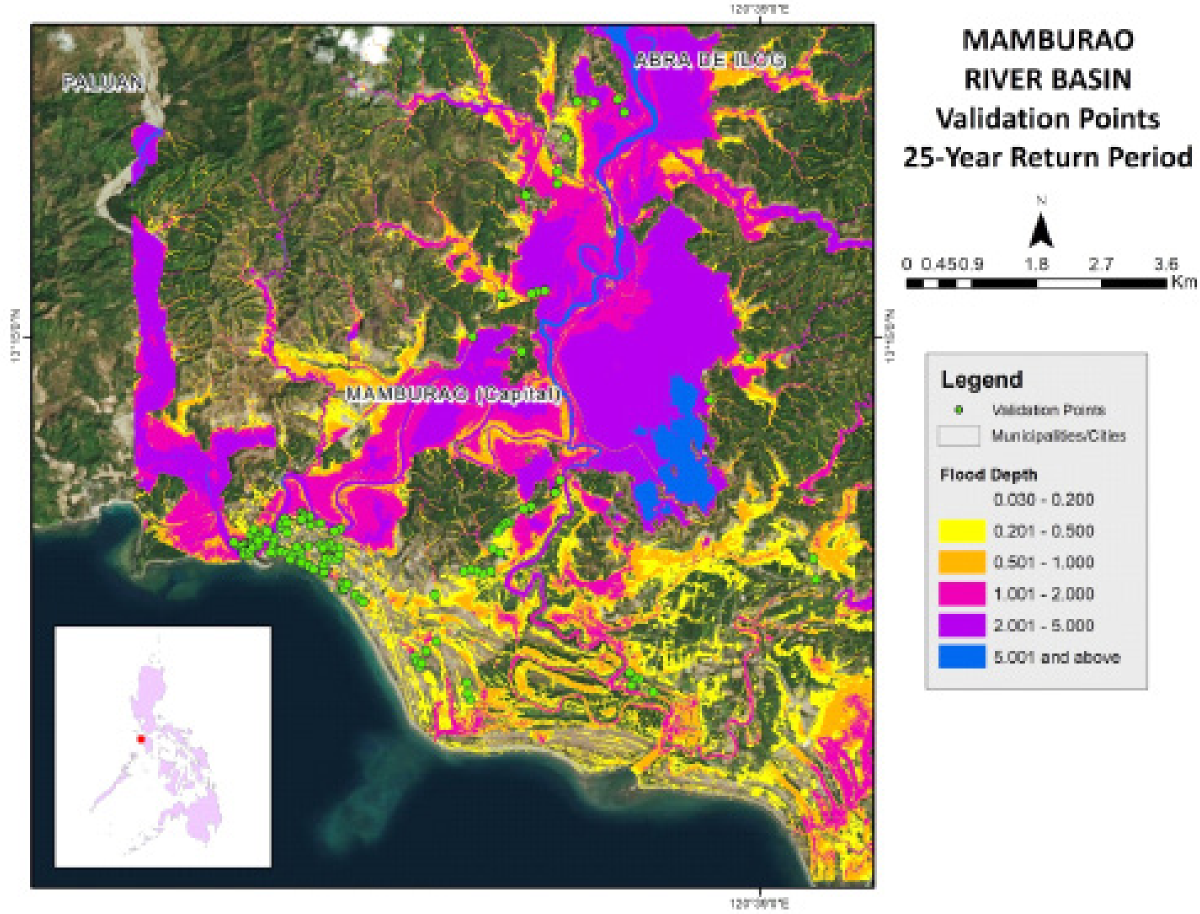

Figure 82. Validation points for 25-year Flood Depth Map of Mamburao Floodplain

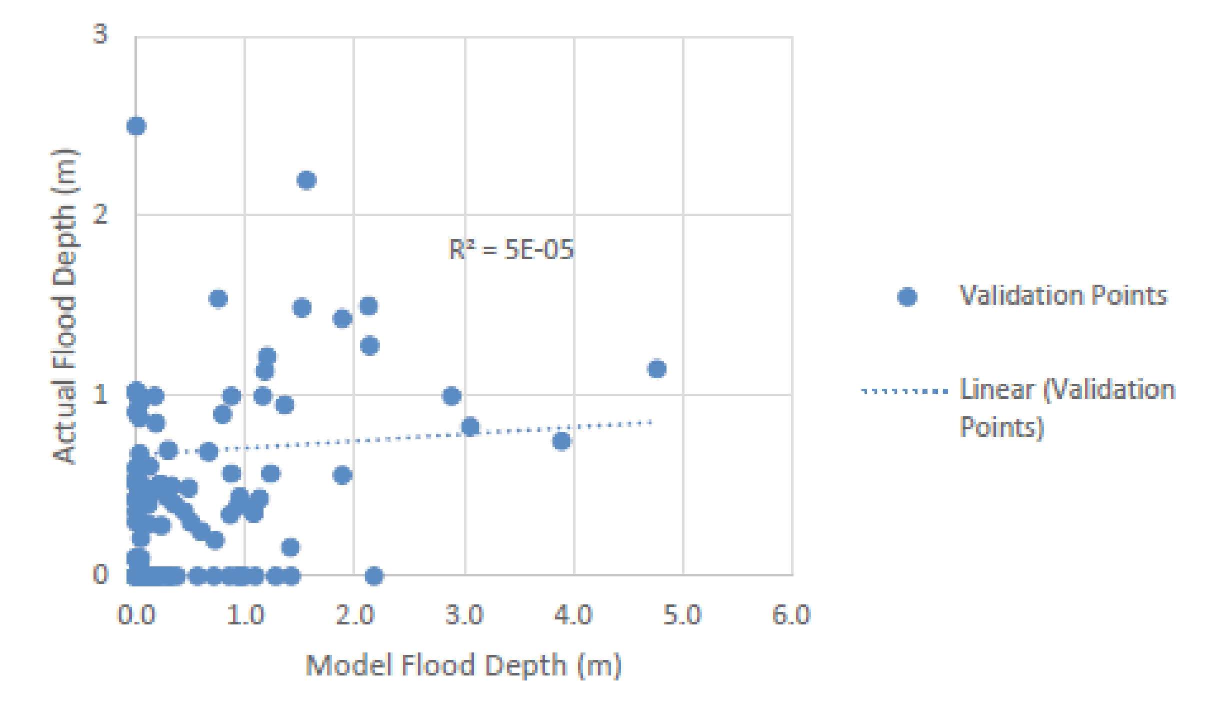

Figure 83. Flood map depth vs actual flood depth

Table 40. Actual Flood Depth vs Simulated Flood Depth at different levels in the Mamburao River Basin.

MAMBURAO BASIN		Modeled Flood Depth (m)						
		0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
Actual Flood Depth (m)	0-0.20	59	6	7	4	1	0	77
	0.21-0.50	16	10	4	4	0	0	34
	0.51-1.00	14	3	4	4	3	0	28
	1.01-2.00	3	0	1	4	3	0	11
	2.01-5.00	1	0	0	1	0	0	2
	> 5.00	1	0	0	0	0	0	1
	Total	94	19	16	17	7	0	153

The overall accuracy generated by the flood model is estimated at 50.33% with 77 points correctly matching the actual flood depths. In addition, there were 35 points estimated one level above and below the correct flood depths while there were 28 points and 10 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 4 points were overestimated while a total of 40 points were underestimated in the modelled flood depths of Mamburao. Table 41 depicts the summary of the Accuracy Assessment in the Mamburao River Basin Survey.

Table 41. Summary of Accuracy Assessment in the Mamburao River Basin Survey

No. of Points		%
Correct	77	**50.33**
Overestimated	36	**23.53**
Underestimated	40	**26.14**
Total	153	**100.00**

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ANNEXES

Annex 1. Technical Specifications of the LIDAR Sensors used in the Mamburao Floodplain Survey

1. AQUARIUS SENSOR

Table A-1.1. Parameters and Specification of Aquarius Sensor

Parameter	Specification
Operational envelope (1,2,3,4)	150-4000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, (m AGL)
Elevation accuracy (2)	<5-35 cm, 1 σ
Effective laser repetition rate	Programmable, 33-167 kHz
Position and orientation system	POS AV™ AP50 (OEM); 220-channel dual frequency GPS/GNSS/Galileo/L-Band receiver
Scan width (WOV)	Programmable, 0-50˚
Scan frequency (5)	Programmable, 0-70 Hz (effective)
Sensor scan product	1000 maximum
Beam divergence	Dual divergence: 0.25 mrad (1/e) and 0.8 mrad (1/e), nominal
Roll compensation	Programmable, ±5˚ (FOV dependent)
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Video Camera	Internal video camera (NTSC or PAL)
Image capture	Compatible with full Optech camera line (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer (optional)
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V; 900 W;35 A(peak)
Dimensions and weight	Sensor: 260 mm (w) x 190 mm (l) x 570 mm (h); 23 kg Control rack: 650 mm (w) x 590 mm (l) x 530 mm (h); 53 kg
Operating temperature	-10˚C to +35˚C (with insulating jacket)
Relative humidity	0-95% no-condensing

2. PEGASUS SENSOR

Table A-1.2. Parameters and Specification of Pegasus Sensor

Parameter	Specification
Operational envelope (1,2,3,4)	150-5000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, 1σ
Elevation accuracy (2)	< 5-20 cm, 1σ
Effective laser repetition rate	Programmable, 100-500 kHz
Position and orientation system	POS AV ™AP50 (OEM)
Scan width (FOV)	Programmable, 0-75 ˚
Scan frequency (5)	Programmable, 0-140 Hz (effective)
Sensor scan product	800 maximum
Beam divergence	0.25 mrad (1/e)
Roll compensation	Programmable, ±37˚ (FOV dependent)
Vertical target separation distance	<0.7 m
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Image capture	5 MP interline camera (standard); 60 MP full frame (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V, 800 W, 30 A
Dimensions and weight	Sensor: 630 x 540 x 450 mm; 65 kg;
	Control rack: 650 x 590 x 490 mm; 46 kg
Operating Temperature	-10°C to +35°C
Relative humidity	0-95% non-condensing

1 . Target reflectivity ≥20%
2 . Dependent on selected operational parameters using nominal FOV of up to 40° in standard atmospheric conditions with 24-km visibility.
3 Angle of incidence ≤20˚
4 Target size ≥ laser footprint5 Dependent on system configuration.

3. D-8900 AERIAL CAMERA

Table A-1.3. Parameters and Specification of D-8900 AERIAL CAMERA

Parameter	Specification
Camera Head	
Sensor type	60 Mpix full frame CCD, RGB
Sensor format (H x V)	8, 984 x 6, 732 pixels
Pixel size	6µm x 6 µm
Frame rate	1 frame/2 sec.
FMC	Electro-mechanical, driven by piezo technology (patented)
Shutter	Electro-mechanical iris mechanism 1/125 to 1/500++ sec. f-stops: 5.6, 8, 11, 16
Lenses	50 mm/70 mm/120 mm/210 mm
Filter	Color and near-infrared removable filters
Dimensions (H x W x D)	200 x 150 x 120 mm (70 mm lens)
Weight	~4.5 kg (70 mm lens)
Controller Unit	
Computer	UMini-ITX RoHS-compliant small-form-factor embedded computers with AMD TurionTM 64 X2 CPU 4 GB RAM, 4 GB flash disk local storage IEEE 1394 Fire wire interface
Removable storage unit	~500 GB solid state drives, 8,000 images
Power consumption	~8 A, 168 W
Dimensions	2U full rack; 88 x 448 x 493 mm
Weight	~15 kg
Image Pre-Processing Software	
Capture One	Radiometric control and format conversion, TIFF or JPEG
Image output	8,984 x 6,732 pixels 8 or 16 bits per channel (180 MB or 360 MB per image)

Annex 2. NAMRIA Certification of Reference Points Used in the LIDAR Survey

1. MRW-30

Republic of the Philippines
Department of Environment and Natural Resources
NATIONAL MAPPING AND RESOURCE INFORMATION AUTHORITY

February 19, 2014

CERTIFICATION

To whom it may concern:

This is to certify that according to the records on file in this office, the requested survey information is as follows -

Province: **OCCIDENTAL MINDORO**
Station Name: **MRW-30**
Order: **2nd**

Island: **LUZON**
Municipality: **SANTA CRUZ**
Barangay: **PINAGTURILAN (SAN PEDRO)**

PRS92 Coordinates

Latitude: 12° 57' 32.22950"	Longitude: 120° 53' 28.50896"	Ellipsoidal Hgt: 42.01300 m.

WGS84 Coordinates

Latitude: 12° 57' 27.19115"	Longitude: 120° 53' 33.54442"	Ellipsoidal Hgt: 89.79300 m.

PTM Coordinates

Northing: 1433011.7 m.	Easting: 488201.05 m.	Zone: 3

UTM Coordinates

Northing: 1,433,451.97	Easting: 271,237.33	Zone: 51

Location Description

MRW-30

From the Sablayan Astrodome, travel N along the Nat'l Road approx. 35 Km. up to Amny bridge, the Station is permanently marked and located at the SE end of the catwalk of Amnay bridge, and about 2 m SE of Km. post 356. Station is located in Brgy. Pinagturilan, Sitio Kabangkalan, Occ. Mindoro. Mark is the head of 4 in. copper nail flushed in a cement block embedded in the ground with inscriptions, "MRW-30, 2007, NAMRIA".

Requesting Party: **UP DREAM**
Purpose: **Reference**
OR Number: **8795394 A**
T.N.: **2014-356**

RUEL DM. BELEN, MNSA
Director, Mapping And Geodesy Branch

NAMRIA OFFICES:
Main : Lawton Avenue, Fort Bonifacio, 1634 Taguig City, Philippines Tel. No.: (632) 810-4831 to 41
Branch : 421 Barraca St. San Nicolas, 1010 Manila, Philippines, Tel. No. (632) 241-3494 to 98
www.namria.gov.ph

Figure A-2.1. MRW-30

2. MRW-32

Republic of the Philippines
Department of Environment and Natural Resources
NATIONAL MAPPING AND RESOURCE INFORMATION AUTHORITY

February 19, 2014

CERTIFICATION

To whom it may concern:

This is to certify that according to the records on file in this office, the requested survey information is as follows -

Province: **OCCIDENTAL MINDORO**
Station Name: **MRW-30**
Order: **2nd**

Island: **LUZON**		Barangay: **PINAGTURILAN (SAN PEDRO)**
Municipality: **SANTA CRUZ**		
	PRS92 Coordinates	
Latitude: **12° 57' 32.22950"**	Longitude: **120° 53' 28.50896"**	Ellipsoidal Hgt: **42.01300 m.**
	WGS84 Coordinates	
Latitude: **12° 57' 27.19116"**	Longitude: **120° 53' 33.54442"**	Ellipsoidal Hgt: **89.78300 m.**
	PTM Coordinates	
Northing: **1433011.7 m.**	Easting: **488201.05 m.**	Zone: **3**
	UTM Coordinates	
Northing: **1,433,451.97**	Easting: **271,237.33**	Zone: **51**

Location Description

MRW-30

From the Sablayan Astrodome, travel N along the Nat'l Road approx. 35 Km. up to Amny bridge, the Station is permanently marked and located at the SE end of the catwalk of Amnay bridge, and about 2 m SE of Km. post 356. Station is located in Brgy. Pinagturilan, Sitio Kabangkalan, Occ. Mindoro. Mark is the head of 4 in. copper nail flushed in a cement block embedded in the ground with inscriptions, "MRW-30, 2007, NAMRIA".

Requesting Party: **UP DREAM**
Pupose: **Reference**
OR Number: **8795394 A**
T.N.: **2014-356**

RUEL DM. BELEN, MNSA
Director, Mapping And Geodesy Branch

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Branch: 421 Barraca St. San Nicolas, 1010 Manila, Philippines, Tel. No. (632) 241-3494 to 98
www.namria.gov.ph

Figure A-2.2. MRW-32

3. MRW-34

Republic of the Philippines
Department of Environment and Natural Resources
NATIONAL MAPPING AND RESOURCE INFORMATION AUTHORITY

February 26, 2014

CERTIFICATION

To whom it may concern:

This is to certify that according to the records on file in this office, the requested survey information is as follows -

Province: **OCCIDENTAL MINDORO**
Station Name: **MRW-34**
Order: **2nd**

Island: **LUZON** Municipality: **ABRA DE ILOG**		Barangay: **ARMADO**
	PRS92 Coordinates	
Latitude: **13° 17' 25.00981"**	Longitude: **120° 37' 41.53630"**	Ellipsoidal Hgt: **8.01600 m.**
	WGS84 Coordinates	
Latitude: **13° 17' 19.87026"**	Longitude: **120° 37' 46.54446"**	Ellipsoidal Hgt: **54.26900 m.**
	PTM Coordinates	
Northing: **1469690.588 m.**	Easting: **459714.493 m.**	Zone: **3**
	UTM Coordinates	
Northing: **1,470,369.33**	Easting: **243,032.08**	Zone: **51**

Location Description

MRW-34

From Abra de Ilog to San Jose, along Nat'l Road approx. 20.3 Km. from Abra de Ilog Town Proper, 300 m from Km. post 418, 9.7 Km. before Mamburao Proper, located Balibago Bridge at Brgy. Armado, Sitio Balibago, Abra de Ilog, Occ. Mindoro. Station is located near footpath of Balibago Bridge. Mark is the head of a 4 in. copper nail flushed in a cement block embedded in the ground with inscriptions, "MRW-34, 2007, NAMRIA".

Requesting Party: **UP DREAM**
Pupose: **Reference**
OR Number: **8795440 A**
T.N.: **2014-396**

For **RUEL DM. BELEN, MNSA**
Director, Mapping And Geodesy Branch

NAMRIA OFFICES:
Main : Lawton Avenue, Fort Bonifacio, 1634 Taguig City, Philippines Tel. No.: (632) 810-4831 to 41
Branch : 421 Barraca St. San Nicolas, 1010 Manila, Philippines, Tel. No. (632) 241-3494 to 98
www.namria.gov.ph

Figure A-2.3. MRW-34

4. MRW-36

Republic of the Philippines
Department of Environment and Natural Resources
NATIONAL MAPPING AND RESOURCE INFORMATION AUTHORITY

February 26, 2014

CERTIFICATION

To whom it may concern:

This is to certify that according to the records on file in this office, the requested survey information is as follows -

Province: **OCCIDENTAL MINDORO**
Station Name: **MRW-36**
Order: **2nd**

Island: **LUZON**		Barangay: **CABACAO**
Municipality: **ABRA DE ILOG**		
	PRS92 Coordinates	
Latitude: **13° 21' 44.07349"**	Longitude: **120° 39' 20.54160"**	Ellipsoidal Hgt: **31.49300 m.**
	WGS84 Coordinates	
Latitude: **13° 21' 38.91908"**	Longitude: **120° 39' 25.54340"**	Ellipsoidal Hgt: **77.62100 m.**
	PTM Coordinates	
Northing: **1477646.985 m.**	Easting: **462705.446 m.**	Zone: **3**
	UTM Coordinates	
Northing: **1,478,304.87**	Easting: **246,088.34**	Zone: **51**

Location Description

MRW-36

From Abra de Ilog to Mamburao, along Nat'l Road, approx. 12.6 Km. from Abra de Ilog Town Proper, 600 m from Km. post 427, 400 m before Km. post 426, located Baclaran Bridge at Brgy. Cabacao, Abra de Ilog, Occ., Mindoro. Station is located near footpath of Baclaran Bridge. Mark is the head of a 4 in. copper nail flushed in a cement block embedded in the ground with inscriptions, MRW-36, 2007, NAMRIA".

Requesting Party:	**UP DREAM**
Pupose:	**Reference**
OR Number:	**8795440 A**
T.N.:	**2014-395**

FOR **RUEL DM. BELEN, MNSA**
Director, Mapping And Geodesy Branch

NAMRIA OFFICES:
Main : Lawton Avenue, Fort Bonifacio, 1634 Taguig City, Philippines Tel. No.: (632) 810-4831 to 41
Branch : 421 Barraca St. San Nicolas, 1010 Manila, Philippines, Tel. No. (632) 241-3494 to 98
www.namria.gov.ph

CIP/0701/12/09/814

Figure A-2.4. MRW-36

ANNEX 3. Baseline Processing Reports of Control Points used in the LIDAR Survey

1. MRWDAC-00

Table A-3.1. MRWDAC-00

Project information		Coordinate System	
Name:		Name:	UTM
Size:		Datum:	PRS 92
Modified:	10/12/2012 4:40:11 PM (UTC:-6)	Zone:	51 North (123E)
Time zone:	Mountain Standard Time	Geoid:	EGMPH
Reference number:		Vertical datum:	
Description:			

Baseline Processing Report

Processing Summary

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
MRWDAC-00 --- MRW-30 (B1)	MRW-30	MRWDAC-00	Fixed	0.003	0.011	312°40'19"	43136.391	-30.412
MRWDAC-00 --- MRW-30 (B2)	MRW-30	MRWDAC-00	Fixed	0.006	0.016	312°40'19"	43136.383	-30.384

Acceptance Summary

Processed	Passed	Flag	Fail
2	2	0	0

MRWDAC-00 - MRW-30 (7:22:03 AM-9:48:26 AM) (S1)

Baseline observation:	MRWDAC-00 --- MRW-30 (B1)
Processed:	12/15/2015 5:32:10 PM
Solution type:	Fixed
Frequency used:	Dual Frequency (L1, L2)
Horizontal precision:	0.003 m
Vertical precision:	0.011 m
RMS:	0.004 m
Maximum PDOP:	2.308
Ephemeris used:	Broadcast
Antenna model:	NGS Absolute
Processing start time:	12/8/2015 7:22:11 AM (Local: UTC+8hr)
Processing stop time:	12/8/2015 9:48:26 AM (Local: UTC+8hr)
Processing duration:	02:26:15
Processing interval:	1 second

Vector Components (Mark to Mark)

From:	MRW-30				
Grid		Local		Global	
Easting	271237.336 m	Latitude	N12°57'32.22951"	Latitude	N12°57'27.19115"
Northing	1433451.575 m	Longitude	E120°53'28.50898"	Longitude	E120°53'33.54442"
Elevation	42.722 m	Height	42.013 m	Height	89.793 m

To:	MRWDAC-00				
Grid		Local		Global	
Easting	239765.834 m	Latitude	N13°13'23.10541"	Latitude	N13°13'17.97946"
Northing	1462963.518 m	Longitude	E120°35'55.10583"	Longitude	E120°36'00.11991"
Elevation	15.198 m	Height	11.601 m	Height	57.961 m

Vector					
ΔEasting	-31481.502 m	NS Fwd Azimuth	312°40'19"	ΔX	30671.804 m
ΔNorthing	29511.543 m	Ellipsoid Dist.	43136.391 m	ΔY	10509.502 m
ΔElevation	-27.524 m	ΔHeight	-30.412 m	ΔZ	28452.496 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.003 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.005 m
σ ΔElevation	0.006 m	σ ΔHeight	0.006 m	σ ΔZ	0.002 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000093026		
Y	-0.0000128686	0.0000223985	
Z	-0.0000041460	0.0000065394	0.0000035058

2. MC-52

Table A-3.2. MC-52

Vector Components (Mark to Mark)

From:	mrw36				
Grid		Local		Global	
Easting	246240.672 m	Latitude	N13°21'38.91908"	Latitude	N13°21'38.91908"
Northing	1478236.407 m	Longitude	E120°39'25.54340"	Longitude	E120°39'25.54340"
Elevation	33.839 m	Height	77.621 m	Height	77.621 m

To:	mc-52				
Grid		Local		Global	
Easting	243198.172 m	Latitude	N13°17'20.53041"	Latitude	N13°17'20.53041"
Northing	1470321.018 m	Longitude	E120°37'46.98588"	Longitude	E120°37'46.98585"
Elevation	11.004 m	Height	54.352 m	Height	54.352 m

Vector					
ΔEasting	-3042.500 m	NS Fwd Azimuth	200°29'07"	ΔX	1630.653 m
ΔNorthing	-7915.388 m	Ellipsoid Dist.	8478.543 m	ΔY	3066.891 m
ΔElevation	-22.835 m	ΔHeight	-23.269 m	ΔZ	-7732.333 m

Standard Errors

Vector errors:					
σ ΔEasting	0.001 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.003 m
σ ΔNorthing	0.001 m	σ Ellipsoid Dist.	0.001 m	σ ΔY	0.006 m
σ ΔElevation	0.007 m	σ ΔHeight	0.007 m	σ ΔZ	0.002 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000108465		
Y	-0.0000166791	0.0000331614	
Z	-0.0000060626	0.0000092050	0.0000035632

2

ANNEX 4. The LiDAR Survey Team Composition

Table A-4.1. The LIDAR Survey Team Composition

Data Acquisition Component Sub-Team	Designation	Name	Agency/ Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Component Project Leader - I	ENGR. CZAR JAKIRI SARMIENTO	UP-TCAGP
		ENGR. LOUIE BALICANTA	
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUNA	UP-TCAGP
FIELD TEAM			
LiDAR Operation, Data Download and Transfer	Supervising SRS (2014)	ENGR. LOVELYN ASUNCION	UP-TCAGP
	Senior Science Research Specialist (SSRS) (2015)	PAULINE JOANNE ARCEO	UP-TCAGP
	Research Associate (RA) (2014)	ENGR. LARAH KRISELLE PARAGAS	UP-TCAGP
		PATRICIA ALCANTARA	
	Research Associate (RA) (2015)	ENGR. GRACE SINADJAN	UP-TCAGP
		ENGR. MILLIE SHANE REYES	
Ground Survey	Research Associate (RA) (2014)	ENGR. GRACE SINADJAN	UP-TCAGP
	Research Associate (RA) (2015)	ENGR. FRANK NICOLAS ILEJAY	
LiDAR Operation	Airborne Security	SGT. BENJIE CARBOLLEDO	PHILIPPINE AIR FORCE (PAF)
		SSG. JOHN ERIC CACANINDIN	
	Pilot	CAPT. JEFF ALAJAR	ASIAN AEROSPACE CORPORATION (AAC)
	Pilot	CAPT. JACKSON JAVIER	
	Pilot	CAPT. JUSTIN REI JOYA	
	Pilot	CAPT. SHERWIN ALFONSO III	

Annex 12. Phil-LiDAR 1 UPLB Team Composition

Project Leader
Asst. Prof. Edwin R. Abucay (CHE, UPLB)

Project Staffs/Study Leaders
Asst. Prof. Efraim D. Roxas (CHE, UPLB)
Asst. Prof. Joan Pauline P. Talubo (CHE, UPLB)
Ms. Sandra Samantela (CHE, UPLB)
Dr. Cristino L. Tiburan (CFNR, UPLB)
Engr. Ariel U. Glorioso (CEAT, UPLB)
Ms. Miyah D. Queliste (CAS, UPLB)
Mr. Dante Gideon K. Vergara (SESAM, UPLB)

Sr. Science Research Specialists
Gillian Katherine L. Inciong
For. John Alvin B. Reyes

Research Associates
Alfi Lorenz B. Cura
Angelica T. Magpantay
Gemmalyn E. Magnaye
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